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HIGH FREQUENCY TRANSMISSION SYSTEM

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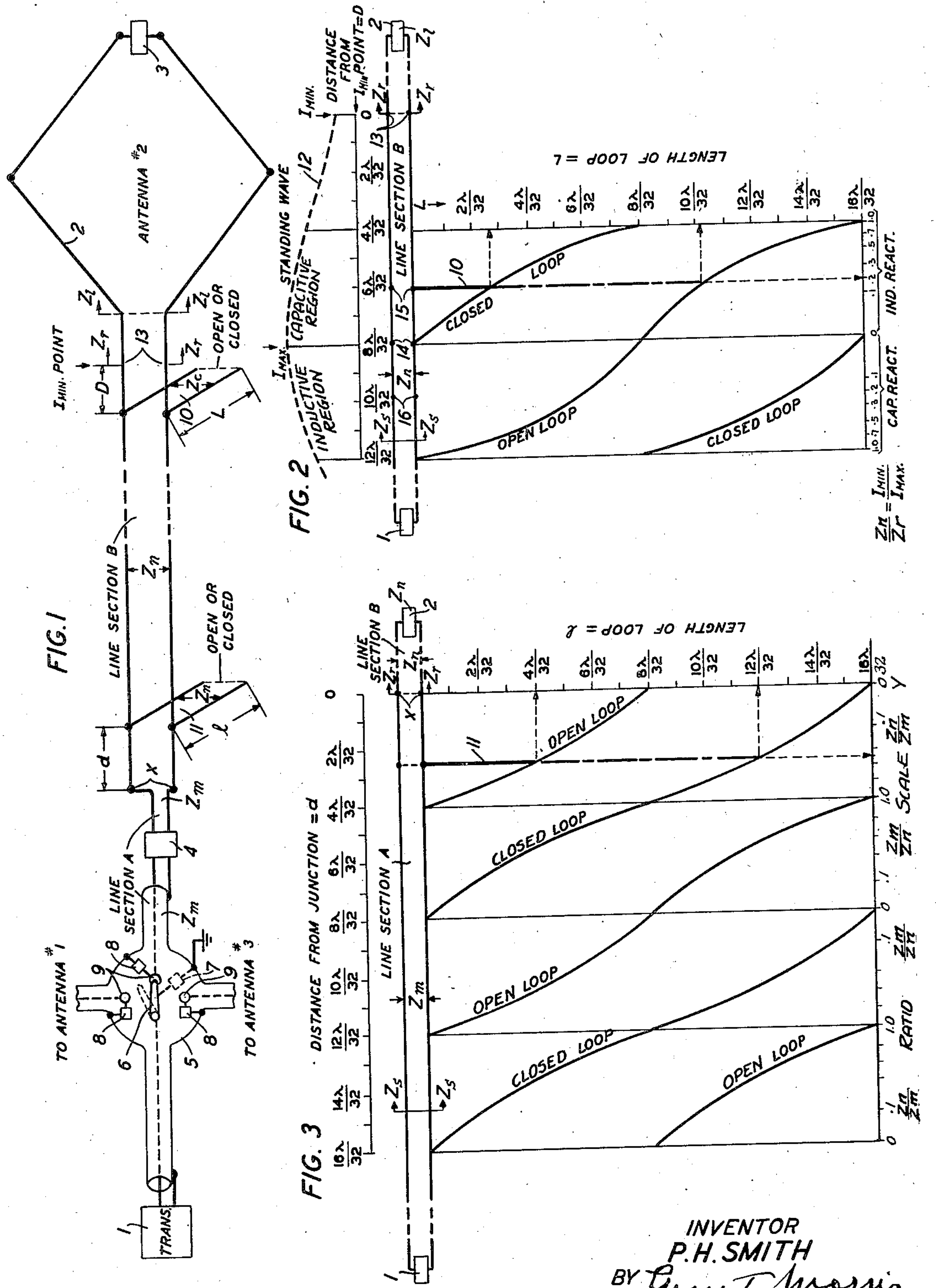

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HIGH FREQUENCY TRANSMISSION SYSTEM

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This invention relates to transmission systems and especially to methods and means for preventing wave reflection in high frequency transmission systems.

In high frequency transmission systems wave reflection which produces line losses and undesired radiation is usually suppressed, in the case of open-ended lines, by terminating the line in a pure resistance equal to the line surge impedance and, in the case of lines terminated for certain reasons in impedances having a value different from that of the surge impedance of the associated line, by employing lumped or distributed impedance transformers, or suppressors comprising series and shunt reactances, which function to match the load to the line. The transformers and suppressors in use at present, aside from being comparatively costly, do not in general accomplish the desired result in an entirely satisfactory manner.

It is one object of this invention to improve the operation of transmission lines in a simple and economical manner.

It is another object of this invention to suppress standing waves on transmission lines in a more effective manner than heretofore achieved and with minimum dissipation losses.

It is a further object of this invention to suppress standing waves on transmission lines produced by auxiliary line apparatus such as switches, insulators and the like.

It is still another object of this invention to suppress standing waves on transmission lines comprising sections having different surge impedances.

According to this invention, standing waves are suppressed on a line connected between a source of high frequency energy and a load having an impedance value substantially different from the line surge impedance by means of a reactance, preferably a distributed reactance in the form of an auxiliary line, connected across the line and critically positioned with respect to a point of maximum standing wave current. The distance between the maximum point and the position of the reactance is not greater than one-eighth of a wave length and is mathematically related to the reactance value, which in auxiliary line reactances corresponds to the length of line, to the ratio of the maximum and minimum current values and to the line surge impedance. For a given ratio and line surge impedance there are two particular values of reactance each corresponding to one particular reactance position with respect to a given maximum current point.

On lines comprising, for example, two sections having different surge impedances standing waves are suppressed on the section adjacent to the load according to the manner explained above and on the other section by means of a reactance also preferably of the auxiliary line type, the reactive value of which is mathematically related to its position with respect to the junction point of the sections and to the ratio of their surge impedances. The reactance may be connected across either section. For given values of surge impedances there are two particular values of reactance each corresponding to a particular position on each section.

Waves produced on transmission lines by the undesired impedance effects of switches and other auxiliary apparatus are suppressed by means of adjustable impedances, one of which is connected electrically to the line at each position of auxiliary apparatus and adjusted to transform the undesired impedance into the characteristic impedance of the line.

The invention will be more fully understood from the following description taken in connection with the drawing in which like reference characters denote elements of similar function, and in which:

Fig. 1 illustrates a high frequency system comprising a line connected between a source of energy and a load and in which the invention is employed for suppressing standing waves on two transmission line sections which have different surge impedances; and

Figs. 2 and 3 are charts which are useful in determining the position and length of the shunt auxiliary line reactances shown in Fig. 1 employed for suppressing waves on the section adjacent to the load and the one adjacent to the source of energy, respectively.

In Fig. 1 reference numeral **1** designates a transmitter which is connected to an antenna designated by numeral **2** by means of a transmission line comprising concentric line section A and open-wire line section B. Reference numeral **3** designates an impedance in which antenna **2** is terminated and numeral **4** denotes apparatus for balancing the impedance of each conductor of the open-wire section to ground. The surge impedance Z_m of line section A is assumed to be different from surge impedance Z_n of line section B and the load or antenna input impedance Z_l is assumed to be unequal to the surge impedance Z_n of line section B. The invention, it should be understood, is not limited to antenna transmission systems as it may be successfully employed in connection with lines associated with any suitable source of energy and any suitable load. It is also particularly useful in suppressing wave reflection resulting from lumped or distributed line impedance irregularities such as that introduced by sharp bends, auxiliary equipment and the like. When the transmission line shown in Fig. 1 is used in a radio receiving system, the antenna **2** may be considered the source of energy and the receiver which replaces the transmitter **1**, the load.

The junction of line sections A and B is denoted by reference letter X. Included in the concentric line section A, the outer conductor of which is grounded, is a switching device **5** comprising switch element **6** for connecting the inner conductor of the branch concentric line associated with the transmitter **1** to the inner conductors of any of the three branch concentric lines associated with antennas Nos. 1, 2 and 3. The undesired impedance introduced by the switch which usually comprises additional capacity between the switching element **6** and the outer conductor or ground, is represented by means of impedance **7** shown in dotted line. Reference numerals **8** designate adjustable impedances having a reactive characteristic opposite that of the undesired impedance **7**, one of the impedances **8** being connected across each branch line at the switch contact **9**.

Two auxiliary transmission lines or transformers designated by the reference numerals **10** and **11** and each having a surge impedance equal to that of line section B are connected across line section No. 2. In accordance with this invention, the length L and distance D from the point of connection of transformer **10** to a given point of maximum standing wave current on the line are such, as will be explained later, that standing waves are suppressed on line section B. Similarly, the length l and distance d of auxiliary line **11** from junction X are such that standing waves are suppressed on line section A. The free or unconnected end of each of these auxiliary lines may be opened or closed depending upon the length of line chosen. The manner of determining the length and position of each of these auxiliary lines will be best understood by considering Figs. 1 and 2 together in connection with transformer **10** and Figs. 1 and 3 together in connection with transformer **11**.

In Fig. 2 the curve **12** represents the standing wave produced on line section B by the load Z_l. Numerals **13** and **14** denote, respectively, the points of minimum and maximum standing wave current. The sending end impedance designated Z_s varies over each half-wave-length and in a direction from a point midway between minimum point **13** and maximum point **14** to the source **1** is substantially capacitive over the first eighth of a wave-length and substantially inductive over the next eighth of a wave-length. For a given value of surge impedance Z_n and a known ratio of maximum and minimum standing wave amplitudes, represented by

$$\frac{I_{max}}{I_{min}}$$

there is a particular point **15** in the capacitive region at which an inductive reactance of a particular value may be connected across the line for the purpose of suppressing standing waves on line section B. Similarly, there is a particular point **16** in the inductive region at which a capacitive reactance may be connected across the line for accomplishing this result. In transmitting systems the distributed type of reactances shown in Fig. 1 are usually more satisfactory than the lumped reactances since, in distributed reactances, only a small portion of the large quantity of energy conveyed by the line is lost through dissipation.

In both the open and closed types of loop the length corresponds to its reactive value and, as shown in Fig. 2, a closed loop has the same reactive value as an open loop which has a length a quarter-wave-length longer. It also has the same reactive value if its length is increased by a half-wave-length or a multiple thereof. By deriving equations expressing the relation of

$$\frac{I_{max}}{I_{min}}$$

D and L for both the open and closed loops and plotting the values of D and L for different values of

$$\frac{I_{max}}{I_{min}}$$

the curves in Fig. 2 were obtained. From these curves it has been determined that the loop must be connected at a point located more than one-eighth and less than three-eighths of a wave-length from a minimum current point in the direction of the source or, in other words, not more than an eighth of a wave-length from a maximum current point. The equations expressing the relation of the ratio

$$\frac{I_{max}}{I_{min}}$$

the distance D and the length L for both types of loops are derived as follows:

In general, the sending end impedance Z_s at any point on a transmission line a distance D from a resistive load Z_r, which type of load exists at a minimum and also at a maximum current point, in the direction of the source is given in Mr. J. A. Fleming's textbook "The Propagation of Electric Current in Telephone and Telegraph Conductors", third edition, page 99, by the equation:

$$Z_s = Z_n \frac{Z_r \cosh PD + Z_n \sinh PD}{Z_n \cosh PD + Z_r \sinh PD} \qquad (1)$$

where Z_n=the characteristic impedance of the line, P=the propagation constant and PD=the propagation length or distance.

But from Equation 45 on page 80 of Mr. Fleming's textbook mentioned above

$$P = \alpha + j\beta$$

where α is the attenuation constant and β is the wave-length constant. See pages 81 and 84 of the above mentioned textbook.

Now, referring to Mr. G. W. Pierce's textbook entitled "Electric Oscillations and Electric Waves", first edition, page 328, we find that Equation 17 on this page applies to our conditions and that

$$\alpha = \frac{r}{2}\sqrt{\frac{C_u}{L_u}}$$

and

$$\beta = \omega\sqrt{L_u C_u}$$

where r, C_u and L_u are the resistance, capacity and inductance per loop unit of length. See bottom of page 328.

But

$$Z_n = \sqrt{\frac{L_u}{C_u}} = \text{surge impedance}$$

(See Equation 24 on page 329 of Mr. Pierce's textbook.)

Therefore

$$\alpha=\frac{r}{2Z_n}$$

Now from Equation 39, page 331 of Mr. Pierce's textbook

$$\beta=\frac{\omega}{V}=\frac{2\pi f}{V}$$

where f is the frequency and V is the velocity of the current

But

$$\frac{f}{V}=\frac{1}{\lambda},$$

where λ is the wave-length

Therefore

$$\beta=\frac{2\pi}{\lambda}$$

consequently,

$$P=\frac{r}{2Z_n}+j\frac{2\pi}{\lambda}$$

and

$$PD=\frac{rD}{2Z_n}+j\frac{2\pi D}{\lambda}$$

Dividing (1) by cosh PD

$$Z_s=Z_n\frac{Z_r+Z_n\ \tanh\ PD}{Z_n+Z_r\ \tanh\ PD} \qquad (2)$$

Assuming a lossless line that is, one in which the loop unit resistance r is exceedingly small or zero so that the I^2r loss per unit length is negligible, then

$$\frac{rD}{2Z_n}=0,\text{ and } PD=j\frac{2\pi D}{\lambda}$$

Also, by transforming to trigonometry, the hyperbolic expression

$$\tanh j\frac{2\pi D}{\lambda}$$

becomes

$$j\tan\frac{2\pi D}{\lambda}$$

Substituting in (2)

$$Z_s=\frac{Z_nZ_r+jZ_n^2\tan\frac{2\pi D}{\lambda}}{Z_n+jZ_r\tan\frac{2\pi D}{\lambda}} \qquad (3)$$

For convenience the resistive load impedance Z_r is taken at a current minimum and its value is given in terms of the surge impedance and the ratio of the standing wave current maximum, I_{max}, and current minimum, I_{min}, by the equation:

$$Z_r=\frac{I_{max}}{I_{min}}Z_n \qquad (4)$$

Substituting in (3)

$$Z_s=\frac{\frac{I_{max}}{I_{min}}Z_n^2+jZ_n^2\tan\frac{2\pi D}{\lambda}}{Z_n+j\frac{I_{max}}{I_{min}}Z_n\tan\frac{2\pi D}{\lambda}} \qquad (5)$$

Now the value of the sending end impedance Z'_s which may be reduced or transformed to Z_n by means of a shunt reactance ($\pm jy$) may be expressed as follows:

$$Z'_s=\frac{\pm jZ_ny}{Z_n\pm jy} \qquad (6)$$

which, by inspection, is the impedance resulting from two impedances (Z_n) and ($\pm jy$) in parallel.

Equating the general expression for Z_s given by Equation (5) and the particular value Z'_s given by equation we have

$$\frac{\pm jZ_ny}{Z_n\pm jy}=\frac{\frac{I_{max}}{I_{min}}Z_n^2+jZ_n^2\tan\frac{2\pi D}{\lambda}}{Z_n+j\frac{I_{max}}{I_{min}}Z_n\tan\frac{2\pi D}{\lambda}} \qquad (7)$$

from which the value of the lumped or distributed shunt reactance ($\pm jy$) and the distance (D) may be determined, the values of Z_n being known from the line design and the ratio

$$\frac{I_{max}}{I_{min}}$$

being experimentally determined.

If the shunt reactance is in the form of an auxiliary line short-circuited at its free end, the value of (jy) at its input terminals, as given in Mr. Fleming's textbook mentioned above on page 97, is

$$jy=Z_c\tanh PL \qquad (8)$$

and for lossless lines

$$jy=jZ_c\tan\frac{2\pi L}{\lambda} \qquad (9)$$

where L/λ represents the length of the closed loop and Z_c the auxiliary line surge impedance.

Substituting in (6)

$$Z'_s=\frac{jZ_cZ_n\tan\frac{2\pi L}{\lambda}}{Z_c+jZ_n\tan\frac{2\pi L}{\lambda}} \qquad (10)$$

Similarly, if the shunt reactance is a lossless auxiliary line open-circuited at the free end, its input impedance is given by the equation:

$$-jy=-jZ_c\cot\frac{2\pi L}{\lambda} \qquad (11)$$

and the particular value of sending impedance Z'_s is given by the equation:

$$Z'_s=\frac{-jZ_cZ_n\cot\frac{2\pi L}{D}}{Z_c-jZ_n\cot\frac{2\pi L}{D}} \qquad (12)$$

Equating the general expression for Z_s as given by Equation (5) for the particular value of Z'_s as given by Equation (10), we have

$$\frac{jZ_cZ_n\tan\frac{2\pi L}{\lambda}}{Z_c+jZ_n\tan\frac{2\pi L}{\lambda}}=\frac{\frac{I_{max}}{I_{min}}Z_n^2+jZ_n^2\tan\frac{2\pi D}{\lambda}}{Z_n+j\frac{I_{max}}{I_{min}}Z_n\tan\frac{2\pi D}{\lambda}} \qquad (13)$$

for the case of the closed loop. This expression is the equation for the curves designated "closed loop" in Fig. 2.

In a similar manner equating the general expression for Z_s as given by Equation (5) for the particular value of Z'_s as given by Equation (12), we have

$$\frac{-jZ_cZ_n\cot\frac{2\pi L}{\lambda}}{Z_c-jZ_n\cot\frac{2\pi L}{\lambda}}=\frac{\frac{I_{max}}{I_{min}}Z_n^2+jZ_n^2\tan\frac{2\pi D}{\lambda}}{Z_n+j\frac{I_{max}}{I_{min}}Z_n\tan\frac{2\pi D}{\lambda}} \qquad (14)$$

for the case of the open loop, which is the equation for the curves denoted "open loop" in Fig. 2.

For convenience Z_c is made equal to Z_n and its value is known. It will be seen that Equations (13) and (14) define the relation between the length (L) and distance (D) from the chosen minimum point for any particular value of

$$\frac{I_{max}}{I_{min}}$$

Referring to the

$$\frac{I_{min}}{I_{max}}$$

or lower scale in Fig. 2 for a given value of this ratio there are two positions on the "distance" or upper scale with respect to the chosen minimum point at which the reactance may be connected, and for each position there is one value of reactance corresponding to different lengths of open and closed auxiliary lines as determined by the "length" or vertical scale.

The distance (D), as given by the curves of Fig. 2, may also be determined as follows.

If, at a particular point in line section B of Fig. 2 there is connected in shunt to the sending impedance Z_s an impedance jy of such value that the resulting impedance is equal to the surge impedance Z_n, the relation may be expressed as follows:

$$Z_n=\frac{(jy)(Z_s)}{jy+Z_s} \qquad (15)$$

and, from Equations 5 and 9, assuming $Z_n=Z_c$, and a closed loop

$$Z_n=\frac{jZ_n \tan\frac{2\pi L}{\lambda}\left[\frac{\left(\frac{I_{max}}{I_{min}}\right)Z_n^2+jZ_n^2\tan\frac{2\pi D}{\lambda}}{Z_n+j\frac{I_{max}}{I_{min}}Z_n\tan\frac{2\pi D}{\lambda}}\right]}{jZ_n\tan\frac{2\pi L}{\lambda}+\left[\frac{\left(\frac{I_{max}}{I_{min}}\right)Z_n^2+jZ_n^2\tan\frac{2\pi D}{\lambda}}{Z_n+j\frac{I_{max}}{I_{min}}Z_n\tan\frac{2\pi D}{\lambda}}\right]} \qquad (16)$$

Let,

$$\frac{I_{max}}{I_{min}}=R$$

$$\tan\frac{2\pi D}{\lambda}=\tan\Delta$$

$$\tan\frac{2\pi L}{\lambda}=\tan\theta$$

Then,

$$Z_n=\frac{jZ_n\tan\theta\left[Z_n\frac{R+j\tan\Delta}{1+jR\tan\Delta}\right]}{jZ_n\tan\theta+Z_n\left[\frac{R+j\tan\Delta}{1+jR\tan\Delta}\right]} \qquad (17)$$

Or,

$$jZ_n\tan\theta\left[Z_n\frac{R+j\tan\Delta}{1+jR\tan\Delta}\right]=jZ_n^2\tan\theta+Z_n^2\left[\frac{R+j\tan\Delta}{1+jR\tan\Delta}\right] \qquad (18)$$

Dividing by

$$Z_n\left[\frac{R+j\tan\Delta}{1+jR\tan\Delta}\right]$$

$$jZ_n\tan\theta=jZ_n\tan\theta\left[\frac{1+jR\tan\Delta}{R+j\tan\Delta}\right]+Z_n \qquad (19)$$

Or,

$$\frac{1+jR\tan\Delta}{R+j\tan\Delta}=\frac{jZ_n\tan\theta-Z_n}{jZ_n\tan\theta} \qquad (20)$$

Rationalizing the left side,

$$\frac{(1+jR\tan\Delta)(R-j\tan\Delta)}{(R+j\tan\Delta)(R-j\tan\Delta)}=\frac{R+R\tan^2\Delta}{R^2+\tan^2\Delta}+j\frac{(R^2\tan\Delta-\tan\Delta)}{(R^2+\tan^2\Delta)} \qquad (21)$$

Rationalizing the right side,

$$\frac{(jZ_n\tan\theta-Z_n)(-jZ_n\tan\theta)}{(jZ_n\tan\theta)\ (-jZ_n\tan\theta)}=1+j\left(\frac{1}{\tan\theta}\right) \qquad (22)$$

Equating the real parts,

$$\frac{R+R\tan^2\Delta}{R^2+\tan^2\Delta}=1 \qquad (23)$$

From which

$$\tan\Delta=\pm\sqrt{R} \qquad (24)$$

That is,

$$\tan\frac{2\pi D}{\lambda}=\pm\sqrt{\frac{I_{max}}{I_{min}}} \qquad (25)$$

Since

$$\frac{I_{max}}{I_{min}}$$

varies from 1 to ∞, tan

$$\frac{2\pi D}{\lambda}$$

varies from +1 to $+\infty$ and from -1 to $-\infty$, and

$$\frac{2\pi D}{\lambda}$$

varies from 45° to 135° or from

$$\frac{\pi}{4}$$

to

$$\frac{3\pi}{4}$$

radians.

When

$$\frac{2\pi D}{\lambda}$$

is a minimum, that is, when

$$\frac{2\pi D}{\lambda}=\frac{\pi}{4}$$

then

$$D=\frac{\lambda}{8}$$

When

$$\frac{2\pi D}{\lambda}$$

is a maximum,

$$D=\frac{3\lambda}{8}$$

Therefore, the distance

$$\left(\frac{D}{\lambda}\right)$$

of the particular point from the I_{min} point is between

$$\frac{\lambda}{8}$$

and

$$\frac{3\lambda}{8}$$

that is, not more than

$$\frac{\lambda}{8}$$

from a I_{max} point.

In a similar manner, using Equation 11, it can be shown that for the case of the open loop the distance

$$\left(\frac{D}{\lambda}\right)$$

is not more than

$$\frac{\lambda}{8}$$

from a I_{max} point.

Referring to Figs. 1 and 3 the function of the junction transformer 11 is to suppress on line section A standing waves produced as a result of terminating this line section in an impedance Z_n at junction X which is unequal to Z_m. Transformer 11 decreases or increases Z_n, depending upon the relative values of Z_n and Z_m, to a value equal to Z_m. The shunt reactance 11 illustrated on the drawing as a distributed impedance may be, if desired, of the lumped type. Furthermore, it may be connected to either section A or section B, the point of connection to either line section being at one of two points lying between zero and a half-wave length from the junction point X. In Fig. 1, the reactance is connected across line B and in Fig. 3 it is schematically represented as being connected across line section A. If, as illustrated, a distributed impedance is employed it may have its free end open or closed and, preferably, its surge impedance is made equal to that of the line section to which it is connected.

Referring to Fig. 3 the sending end impedance Z_s at any point on the line section A a distance d from the load Z_r at junction 4 in the direction of the source is, assuming a lossless line, given by the following equation which corresponds to equation 3 above:

$$Z_s=\frac{Z_mZ_r+jZ_m^2\tan\frac{2\pi d}{\lambda}}{Z_m+jZ_r\tan\frac{2\pi d}{\lambda}} \tag{26}$$

Since the input impedance to the junction is a resistance equal to the surge impedance Z_n of line section B

$$Z_r=Z_n=Z_n\frac{Z_m}{Z_m}=\left(\frac{Z_n}{Z_m}\right)Z_m \tag{27}$$

and substituting in (15)

$$Z_s=\frac{\left(\frac{Z_n}{Z_m}\right)Z_m^2+jZ_m^2\tan\frac{2\pi d}{\lambda}}{Z_m+j\left(\frac{Z_n}{Z_m}\right)Z_m\tan\frac{2\pi d}{\lambda}} \tag{28}$$

As before, the particular value Z'_s of Z_s which may be reduced or transformed to Z_m by means of shunt reactance ($\pm jy$) may be expressed by:

$$Z'_s=\frac{\pm jZ_my}{Z_m\pm jy} \tag{29}$$

which, by inspection, is the impedance resulting from the two impedances Z_m and $\pm jy$ in parallel.

Equating (17) and (18)

$$\frac{\pm jZ_my}{Z_m\pm jy}=\frac{\left(\frac{Z_n}{Z_m}\right)Z_m^2+jZ_m^2\tan\frac{2\pi d}{\lambda}}{Z_m+j\left(\frac{Z_n}{Z_m}\right)Z_m\tan\frac{2\pi d}{\lambda}} \tag{30}$$

from which the value of the lumped or distributed shunt reactance (jy) and the distance (d) to the junction 4 may be determined, the ratio of surge impedance

$$\frac{Z_n}{Z_m}$$

being known from the design of the line sections.

If the shunt reactance is in the form of an auxiliary line, as illustrated by line 11, short-circuited at its free end and having a characteristic impedance equal to Z_m the input reactance (jy) is expressed for a lossless line as:

$$jy=jZ_m\tan\frac{2\pi l}{\lambda} \tag{31}$$

where l/λ is the length of auxiliary line, substituting in (18)

$$Z'_s=\frac{jZ_m^2\tan\frac{2\pi l}{\lambda}}{Z_m+jZ_m\tan\frac{2\pi l}{\lambda}} \tag{32}$$

Similarly, for a lossless open-circuited auxiliary line,

$$-jy=-jZ_m\cot\frac{2\pi l}{\lambda} \tag{33}$$

and,

$$Z'_s=\frac{-jZ_m^2\cot\frac{2\pi l}{\lambda}}{Z_m-jZ_m\cot\frac{2\pi l}{\lambda}} \tag{34}$$

Equating the general expression for Z_s as given by Equation (17) to the particular values as given by Equations (21) and (23) we have for the case of the closed loop

$$\frac{jZ_m^2\tan\frac{2\pi l}{\lambda}}{Z_m+jZ_m\tan\frac{2\pi l}{\lambda}}=\frac{\left(\frac{Z_n}{Z_m}\right)Z_m^2+jZ_m^2\tan\frac{2\pi d}{\lambda}}{Z_m+j\left(\frac{Z_n}{Z_m}\right)Z_m\tan\frac{2\pi d}{\lambda}} \tag{35}$$

or,

$$\frac{j\tan\frac{2\pi l}{\lambda}}{1+j\tan\frac{2\pi l}{\lambda}}=\frac{\frac{Z_n}{Z_m}+j\tan\frac{2\pi d}{l}}{1+j\frac{Z_n}{Z_m}\tan\frac{2\pi d}{l}} \tag{36}$$

which is the equation for the curves in Fig. 3 designated "closed loop", and we have for the open loop

$$\frac{-jZ_m^2\cot\frac{2\pi l}{\lambda}}{Z_m-jZ_m\cot\frac{2\pi l}{\lambda}}=\frac{\left(\frac{Z_n}{Z_m}\right)Z_m^2+jZ_m^2\tan\frac{2\pi d}{\lambda}}{Z_m+j\left(\frac{Z_n}{Z_m}\right)Z_m\tan\frac{2\pi d}{\lambda}} \tag{37}$$

or,

$$\frac{-j\cot\frac{2\pi l}{\lambda}}{1-j\cot\frac{2\pi l}{\lambda}}=\frac{\frac{Z_n}{Z_m}+j\tan\frac{2\pi d}{\lambda}}{1+j\frac{Z_n}{Z_m}\tan\frac{2\pi d}{\lambda}} \tag{38}$$

which is the equation for the curves in Fig. 3 designated "open loop".

Equations (36) and (38) it will be observed define the relation between the length of auxiliary line (l) and distance (d) from the junction in wave-lengths for different values of the ratio

$$\frac{Z_n}{Z_m}$$

and from these equations the curves in Fig. 3 are obtained. For convenience, the half wave-length portion of line section A extending from Z_r toward source 1, and the associated curves, may be divided into four quadrants each a

$$\frac{\lambda}{8}$$

wide and the first of which is immediately adjacent Z_r. These curves show that if Z_m is larger than Z_n that is, if

$$\frac{Z_n}{Z_m}>1,$$

and the shunt reactance is to be connected across line section A, it should be connected at one of two points, one of which is located in the first quadrant at a distance 0 to

$$\frac{\lambda}{8}$$

from junction 4 and the other of which is located in the fourth quadrant at a distance

$$\frac{3\lambda}{8}$$

to

$$\frac{\lambda}{2}$$

from junction X. See the bottom scale. Since the ratio

$$\frac{Z_n}{Z_m}$$

is, in a given case, known the two proper distances,

$$\frac{d}{\lambda}$$

and the lengths of both the open and closed loops corresponding to these two distances may be determined from the curves of these two quadrants.

If Z_m is smaller than Z_n, that is, if

$$\frac{Z_m}{Z_n}>1,$$

and the reactance is to be connected to line section A, it should be connected at one of two points, one of which is positioned in the second quadrant at a distance

$$\frac{\lambda}{8}$$

to

$$\frac{\lambda}{4}$$

from junction X and the other of which is located in the third quadrant at a distance of

$$\frac{\lambda}{4}$$

to

$$\frac{3\lambda}{8}$$

from junction X.

The auxiliary line may be connected across line section B instead of line section A. When this arrangement is employed, the source 1 and the load Z_n are in effect interchanged in accordance with the reciprocity theorem. See "Principles of Transmission Networks" by T. Shea, page 52. Consequently, if Z_n is larger than Z_m and the reactance is to be connected to line section B, it should be connected at one of two points one of which is located in the first quadrant of line section B at a distance of 0 to

$$\frac{\lambda}{8}$$

from junction X and the other of which is located in the fourth quadrant at a distance of

$$\frac{3\lambda}{8}$$

to

$$\frac{\lambda}{2}$$

from the junction. If Z_m is larger than Z_n and the reactance is to be connected to line section B it should be positioned in the second or third quadrant at a distance from

$$\frac{\lambda}{8}$$

to

$$\frac{3\lambda}{8}$$

from junction X.

In general, the curves of Fig. 3 apply when the auxiliary line is connected across line section A or line section B. They apply specifically when the auxiliary line, line 11, is connected to the line section which is adjacent to the oscillator 1. By interchanging, in accordance with the reciprocity theorem mentioned above, oscillator 1 and load 2, line sections A and B, and the numerators and denominators of the impedance ratios given in the bottom scale, these curves specifically apply to the case when line 11 is connected to the line section adjacent to the load.

The distance (*d*) as given by the curves of Fig. 3 may also be determined in a manner similar to that described in connection with the distance (D) of Fig. 2.

In Fig. 3, the value of the shunt auxiliary line impedance jy must be such that, when added in parallel to the line sending end impedance Z_s of line section A, the resulting impedance is equal to the surge impedance Z_m. The relation may be expressed:

$$Z_m=\frac{jyZ_s}{jy+Z_s} \tag{39}$$

From Equations 18 and 31, which correspond respectively, to Equations 5 and 9

$$Z_m=\frac{jZ_m\tan\frac{2\pi l}{\lambda}\left[\frac{\left(\frac{Z_n}{Z_m}\right)Z_m^2+jZ_m^2\tan\frac{2\pi d}{\lambda}}{Z_m+j\left(\frac{Z_n}{Z_m}\right)Z_m\tan^2\frac{2\pi d}{\lambda}}\right]}{jZ_m\tan\frac{2\pi l}{\lambda}\left[\frac{\left(\frac{Z_n}{Z_m}\right)Z_m^2+jZ_m^2\tan\frac{2\pi d}{\lambda}}{Z_m+j\left(\frac{Z_n}{Z_m}\right)Z_m\tan\frac{2\pi d}{\lambda}}\right]} \tag{40}$$

for the case of the closed loop.

It will be noted that the above equation is similar to Equation (16).

From Equation (40)

$$\tan\frac{2\pi d}{\lambda}=\pm\sqrt{\frac{Z_n}{Z_m}} \tag{41}$$

The ratio

$$\frac{Z_n}{Z_m}$$

is either smaller or greater than unity. If it is smaller,

$$\tan\frac{2\pi d}{\lambda}$$

varies from 0 to +1 and from −1 to 0, and (*d*) varies correspondingly from 0 to

$$\frac{\lambda}{8}$$

and from

$$\frac{3\lambda}{8}$$

to

$$\frac{\lambda}{2}$$

If

$$\frac{Z_n}{Z_m}$$

is greater than unity,

$$\tan\frac{2\pi d}{\lambda}$$

varies from +1 to +∞ and from −∞ to −1, and (*d*) varies from

$$\frac{\lambda}{8}$$

to

$$\frac{\lambda}{4}$$

and from

$$\frac{\lambda}{4}$$

to

$$\frac{3\lambda}{8}$$

Similarly using Equation 33 it can be shown that (*d*) varies the same for the case of the open loop.

It has thus been shown that in accordance with this invention standing waves may be suppressed in a manner employing simple apparatus on a line terminated in a load unequal to the line surge impedance and on a line terminating in another line of different surge impedance. Referring to Fig. 1, it will now be seen that waves produced by insulators, sleeves and switches, such as switch **5**, may also be suppressed by means of a simple irregularity transformer. The effect of inserting such auxiliary equipment is to decrease or increase the unit capacity between the line conductors, or the unit inductance; and in order to overcome the effect, a shunt element of proper value is connected to the line at the position of the disturbing apparatus. Assuming that the line irregularity of switch **5** is capacitive, impedance **8** is made inductive and connected across the line at the switch, the inductance forming with the undesired capacity an anti-resonant circuit at the frequency of the standing waves. By proper adjustment of the impedance **8**, the line impedance at the position of the auxiliary equipment may be rendered substantially similar to the characteristic impedance of the line whereby the line irregularity is substantially removed. If the irregularity is inductive, the impedance **8** is made capacitive. Obviously impedance **8** may be in the form of a distributed impedance.

Although the invention has been described in connection with certain specific embodiments, it is to be understood that the methods and means of the invention are not to be limited to these specific embodiments. The invention may be employed in any high frequency transmission system and the shunt transformers may be of types other than those illustrated without exceeding the scope of the invention.

What is claimed is:

1. A method of preventing standing waves on a portion of a transmission line connected between a source of energy and a load utilizing a substantially pure reactance which comprises determining the ratio of the maximum and minimum standing wave amplitudes, ascertaining a current maximum point on said line and connecting a pure reactance having a value dependent upon said ratio across the line at a point located at a distance from the ascertained current maximum point dependent upon said ratio and less than an eighth of a wave length.

2. A method of preventing wave reflection on at least a portion of a transmission line connected between a source of energy and a load, utilizing a reactance, which comprises determining one or more points at which the standing wave has a maximum amplitude, selecting a particular point not more than an eighth of a wave-length from at least one of the points of maximum amplitude, determining the characteristic and value of reactance corresponding to the particular point from the relation illustrated by the curves on the drawing and connecting a reactance having a characteristic and a value, as so determined, across the line at said particular point.

3. A method of preventing wave reflection on at least a portion of a transmission line connected between a source of energy and a load utilizing a substantially pure reactance which comprises determining one or more points at which the standing wave has a maximum amplitude, ascertaining the ratio of the standing wave maximum and minimum amplitudes and connecting said impedance across the line at a point located at a distance less than one-eighth of a wave-length from at least one of the points of maximum amplitude and depending upon said ratio.

4. A method of preventing wave reflection on a transmission line section conveying waves having a wave-length λ and connected between a source of energy and an effectively resistive load utilizing an impedance which comprises connecting the impedance across said section at a point located more than

$$\frac{\lambda}{8}$$

and less than

$$\frac{3\lambda}{8}$$

from the load when said load is larger than the characteristic impedance of the section or when the converse is true at a point located not more than

$$\frac{\lambda}{8}$$

or at a point located more than

$$\frac{3\lambda}{8}$$

and less than

$$\frac{\lambda}{2}$$

from the load.

5. A method of preventing wave reflection on a transmission line section conveying waves having a wave-length λ and connected between a source of energy and another section terminated in a surge impedance, which comprises connecting the impedance across the second mentioned section at a point located more than

$$\frac{\lambda}{8}$$

and less than

$$\frac{3\lambda}{8}$$

from the junction of said section when said surge impedance is smaller than the characteristic impedance of the first-mentioned line or, when the converse is true, at a point located not more than

$$\frac{\lambda}{8}$$

or more than

$$\frac{3\lambda}{8}$$

and less than

$$\frac{\lambda}{2}$$

from the junction.

6. A method of preventing wave reflection on a transmission line having a given surge impedance and connected between a source of energy and another line terminated in its surge impedance which differs from the first mentioned impedance, utilizing a reactance which comprises selecting a suitable value of reactance and connecting the reactance across the second mentioned line at a point corresponding to the value of reactance selected and positioned not more than a half-wave-length from the junction of said lines.

7. A method of preventing wave reflection on a transmission line comprising sections having different surge impedances and connected between a source of energy and a load utilizing reactances which comprises determining a point in the section adjacent to the load at which the standing wave has a maximum value, connecting one of the reactances across said section at a point not more than one-eighth of a wave-length from said maximum point, and connecting another of the reactances across one of said sections

at a point not more than a half-wave-length from the junction of said portion.

8. A method of preventing wave reflection on a line connected between an antenna and a translation device and containing sections having different surge impedances and auxiliary apparatus utilizing reactances which comprises determining a point on the section adjacent to the antenna at which the standing wave has a maximum amplitude, connecting a reactance across said section at a point positioned not more than one-eighth of a wave-length from the first mentioned point, connecting another reactance across one of two sections forming each junction and at a point not more than a half-wave-length from the junction, connecting an adjustable reactance across the line at each point where the auxiliary apparatus is positioned, and adjusting said last mentioned reactance to compensate for the undesired reactance effect of the associated auxiliary apparatus.

9. In combination, a source of energy, a load, a transmission line connected therebetween and bearing standing waves, and means for suppressing said standing waves comprising a pure reactance having a value dependent upon the ratio of the standing wave maximum and minimum amplitudes, said reactance being connected across the line at a point located not more than an eighth of a wave-length from another point on said line at which the standing wave has a maximum amplitude and at a distance from said last mentioned point dependent upon said ratio.

10. In combination, a source of energy, a load, a transmission line connected therebetween bearing standing waves, and means for suppressing said standing waves comprising an auxiliary line connected across the transmission line at a point not more than an eighth of a wave-length from another point on said transmission line at which the standing wave has a maximum amplitude, said auxiliary line having an input reactive characteristic opposite to that of the line at the point of connection.

11. In combination, a source of energy, a load, a transmission line connected therebetween bearing standing waves, and means for suppressing said standing waves comprising an auxiliary line having a surge impedance equal to that of the transmission line and a particular length, said auxiliary line being connected across the transmission line at a point corresponding to its length and not more than an eighth of a wave-length from a point on the transmission line at which the standing wave has a maximum amplitude.

12. In combination, a source of energy, a load, a transmission line connected therebetween comprising sections having different surge impedances, and means for suppressing wave reflection on the portion adjacent to the source comprising a reactance connected across the portion adjacent to the load at a point not more than a half-wave-length from the junction of said portions.

13. In combination, a source of energy, a resistance load, and a transmission line connected therebetween, said load having a value other than that of the surge impedance of the line, and means for suppressing wave reflection on the line comprising an auxiliary line having a surge impedance equal to that of the line and a particular length, said auxiliary line being connected across the line at a point corresponding to the length of the auxiliary line and not more than an eighth of a wave-length from a point at which the standing wave has a maximum amplitude.

14. In combination, a source of energy, a load, and a transmission line connected therebetween comprising portions having different surge impedances, one of the portions being terminated in its surge impedance, and means for suppressing wave reflection on the other portion comprising an auxiliary line having a surge impedance equal to that of the second mentioned portion and a particular length, said auxiliary line being connected across the second mentioned portion at a point corresponding to the length of the auxiliary length and not more than a half-wave-length from the junction of the two lines.

15. In combination, a source of energy, a load, a line comprising portions having different surge impedances connected therebetween, means for suppressing wave reflection on the portion adjacent the load comprising a reactance connected across said portion at a point located not more than an eighth of a wave length from another point on said portion at which the standing wave has the maximum amplitude, and means for suppressing wave reflection on another portion connected to the first portion comprising a reactance connected across one of the two portions at a point not more than a half wave length from the junction of said portions.

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