Feb. 21, 1939. A. ALFORD 2,147,807

TRANSMISSION LINE

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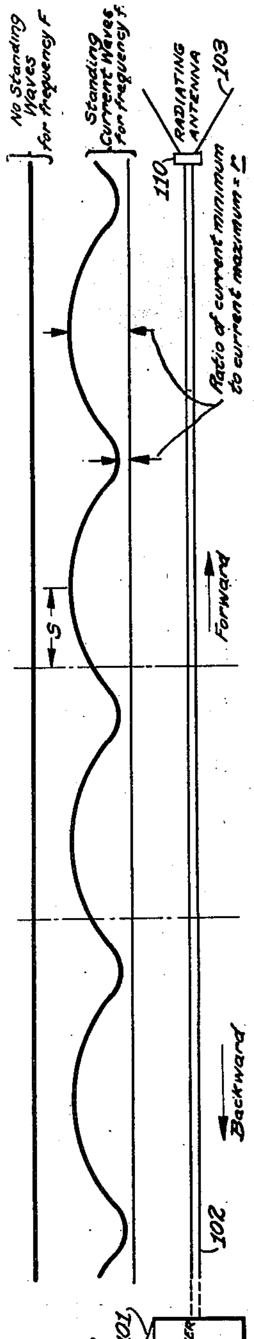

FIG.1.

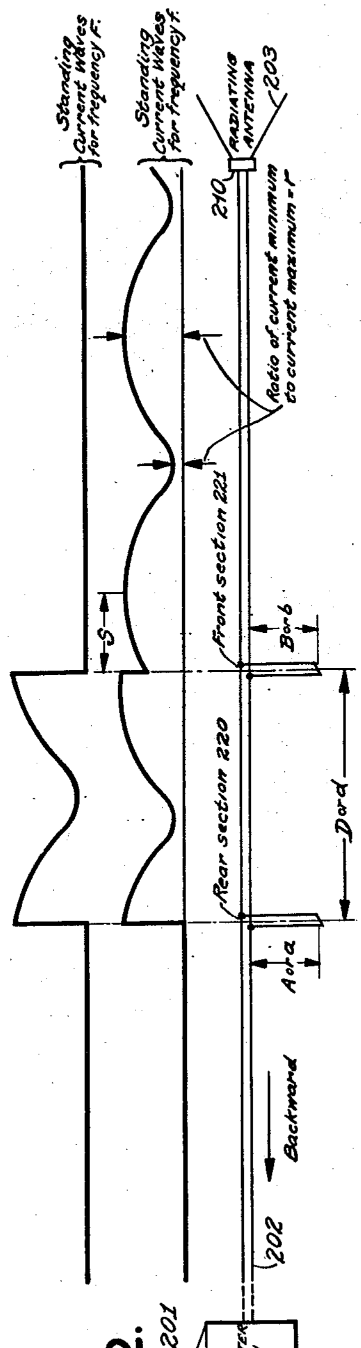

FIG.2.

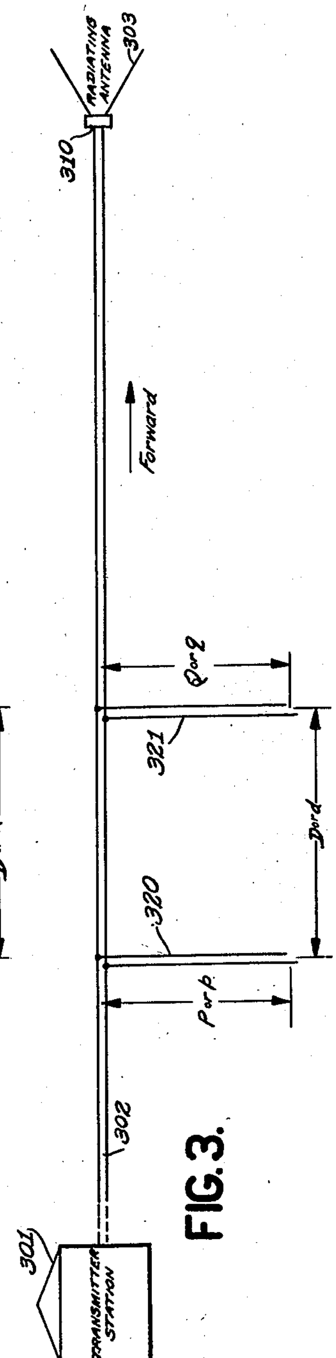

FIG.3.

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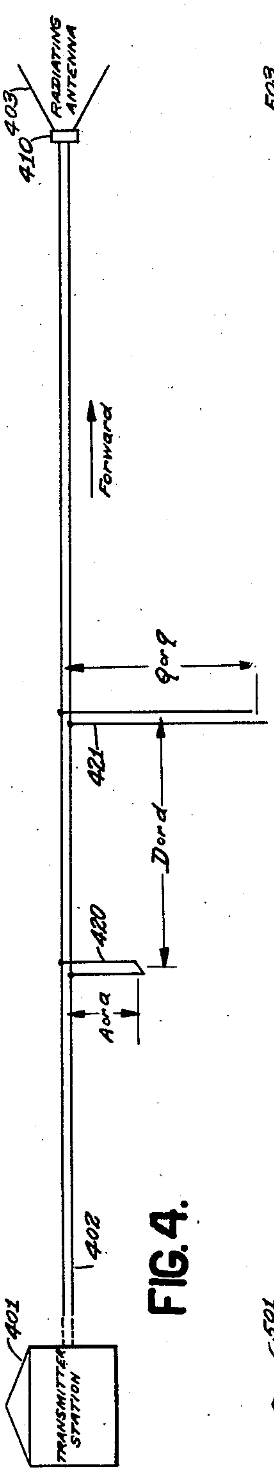

FIG. 4.

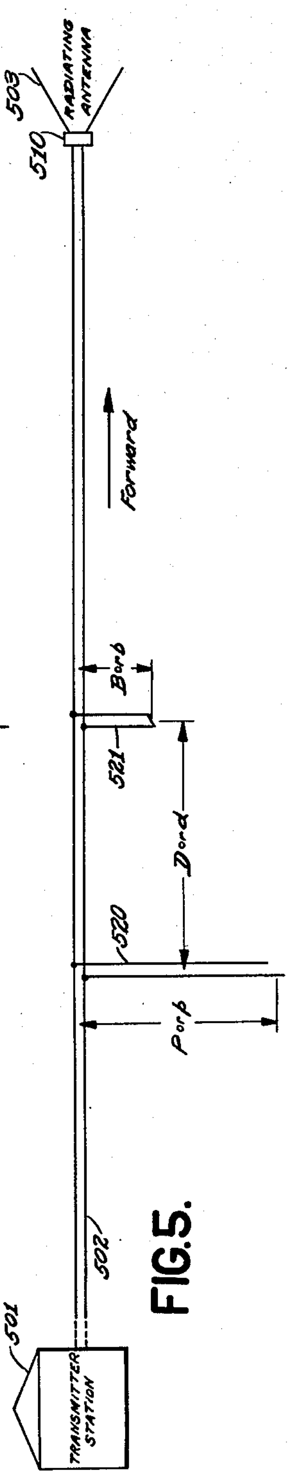

FIG. 5.

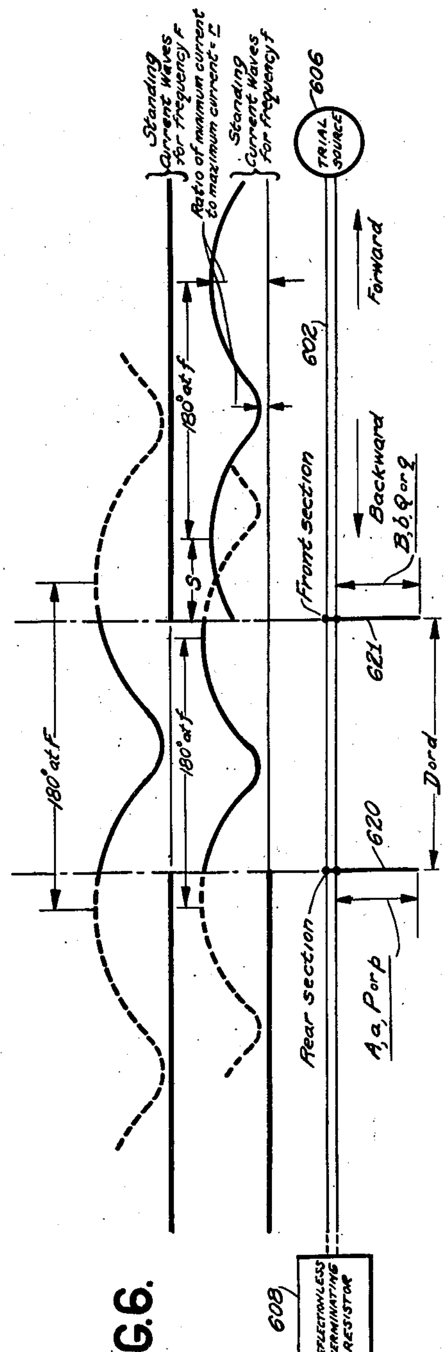

FIG. 6.

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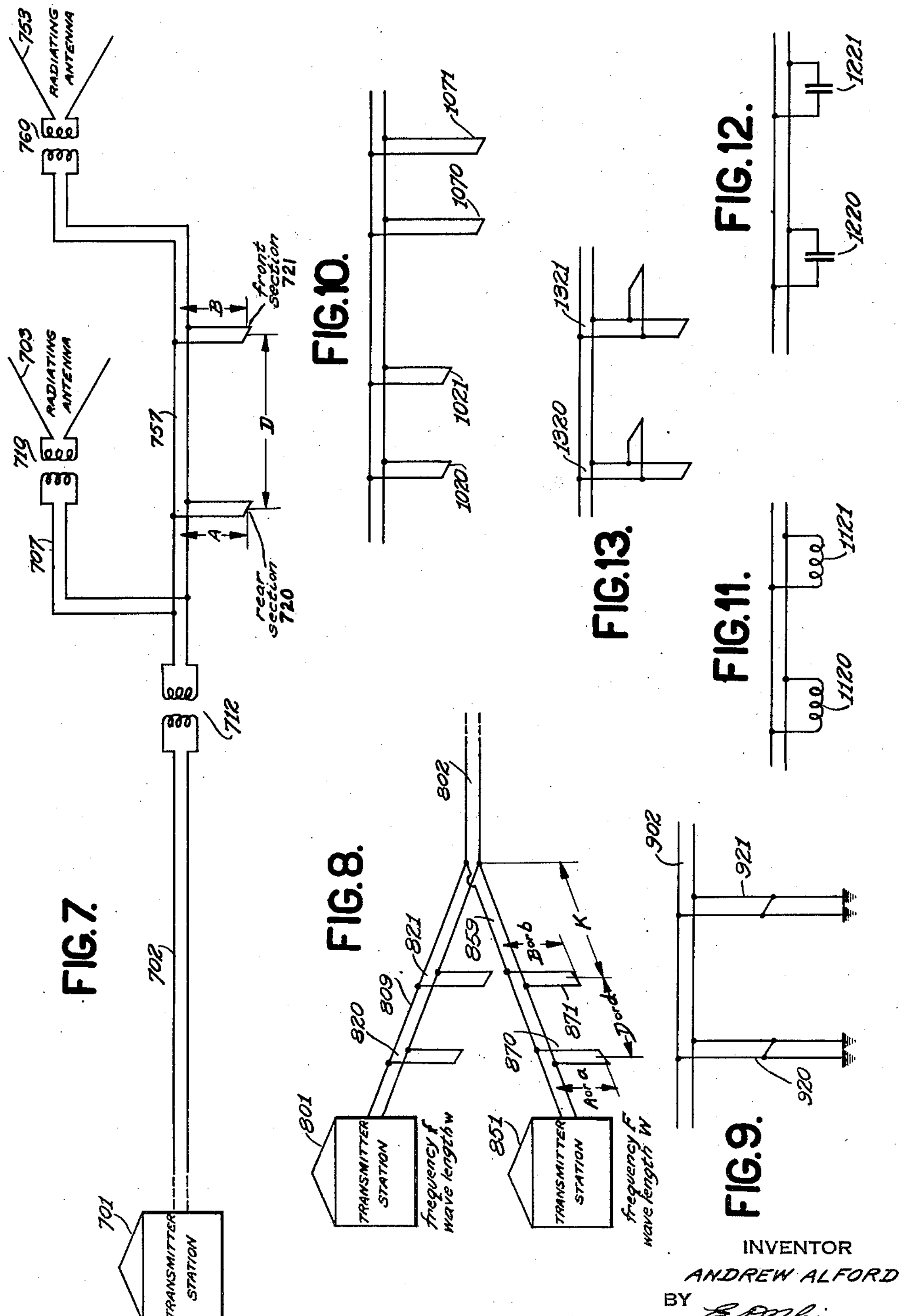

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UNITED STATES PATENT OFFICE

2,147,807

TRANSMISSION LINE

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Application November 7, 1936, Serial No. 109,658

15 Claims. (Cl. 178—44)

This invention relates to a transmission adjuster device used with transmission lines to serve somewhat the same purposes ordinarily served by transformers, filters and the like.

Generally the object of the present invention is to provide a structure which may be readily applied to a transmission line for altering the transmission of waves thereon in certain respects without producing any alteration in other respects. More specifically it is an object to provide a circuit arrangement of impedances applied to a transmission line in such a way that no change in attenuation or reflection will be produced for waves of a particular frequency F, but such that other desired changes in the transmission of the same waves or of other waves will be effected.

One particular object of the present invention is to provide a simple arrangement to be applied to a transmission line which is subjected to only one frequency F for altering the phase of waves of that frequency transmitted along a line without altering any of the other characteristics of the transmission of those waves.

Another particular object is to provide a simple arrangement to be applied to a transmission line which is subjected to two different frequencies so as to sharply alter the transmission characteristics for the waves of one frequency *f* without altering in any important particular the transmission of waves of the other frequency F.

The method and means for accomplishing these objects may be useful in many different fields and it is the purpose of the present invention to provide arrangements for accomplishing these objects in all the different types of systems in which such a selective influence on transmission may be desirable.

In particular, however, it is the purpose of the present invention to provide a simple structure for use in transmission lines connected to radio transmitting or receiving antennae and the embodiments hereinafter described to illustrate the present invention have therefore been disclosed in connection with radio transmitting antenna systems.

In comparison with other arrangements for altering the transmission along the transmission line the structure of the present invention presents the great advantages that the transmission line itself is employed as part of the network so that the additional portions which must be affixed thereto may be of much smaller dimensions than with other types of "phase shifting" or "building-out" arrangements. Also, the present arrangement is adapted to be applied to a transmission line without cutting the transmission line and is arranged so that it may be readily adjusted along the transmission line. Furthermore, the present structure also presents marked advantages from the standpoint of resonant potentials. As will be understood from the description and analysis of the system given below, the present arrangement can readily be designed to avoid the occurrence of unduly high standing wave potentials which might result in corona losses or even flash-over.

In accordance with the present invention two impedances are connected to a transmission line each of the impedances being applied in shunt across the line. The impedance values and the spacing between these two impedances are so adjusted that for one particular frequency the transmission of waves along the line will take place just as if the impedances were not connected thereto, except that the phase of said waves will sometimes generally be altered. In the section of the line between the two impedances the distribution will, it is true, be considerably altered but with respect to those portions of the line outside the impedances substantially no reflections or attenuations will be produced, but only in some cases a change of phase. Two impedances connected and proportioned in this manner ar_ hereinafter referred to as "conjugate" with respect to the frequency for which the attenuations and reflections are unaffected.

In accordance with one embodiment of my invention, this above described structure or combination of two impedances with a transmission line is made use of for adjusting the relative phases of the waves in two antennae fed from the same source and employed as an array for directive transmission.

According to other embodiments of the invention, this same structure is employed in a transmission line used for feeding a single antenna at two different frequencies, the function of the conjugate impedances in this case being to match the impedance of the antenna to the characteristic impedance of the line at one frequency in such a way that the matching or mismatching which would exist at the other frequency in the absence of these impedances remains undisturbed. This will be true whether the two frequencies are applied separately or together.

According to still other embodiments of the invention, this same type of structure is employed for blocking or completely preventing the passage of an undesired frequency *f* along a certain portion of transmission line while permitting the transmission of another desired frequency F over this same portion of line. In fact, by the use of this structure, the transmission of the desired frequency F is not only not blocked but is completely unaffected by the presence of the impedances which serve to block the frequency *f*.

According to still another embodiment of the invention, this same type of structure is employed for grounding a transmission line as a protection against lightning, stray potentials, or surges.

In many cases, several of the objects described above may be simultaneously obtained by the use of the present invention. Referring now more particularly to the drawings, Fig. 1 represents a transmitting system comprising a transmission line subjected to two different frequencies, F and *f*, and shows the nature of the disturbances which may exist along such a line before the impedance matching means of the present invention are applied. Fig. 2 illustrates the same transmitting system after the application of the present invention and shows how the standing wave disturbances which existed in Fig. 1 are modified by means of the present invention. Figs. 3, 4, and 5 illustrate alternative forms of the present invention which are slightly different in construction from that shown in Fig. 2 but are substantially equivalent in effect. Fig. 6 represents a set-up for empirical measurements which may be employed for determining the proportions and dimensions of the structures shown in Figs. 2, 3, 4 and 5. This figure (Fig. 6) also includes a representation of the standing waves which occur in different portions of the transmission line and is dimensioned so as to aid in understanding the formulae for proportioning the different parts. Fig. 7 represents a transmitting system in which two antennae are fed from a single source. In this figure, a pair of conjugate impedances according to the present invention are employed for adjusting the phase of one of these antennae relative to the phase of the other antenna. Fig. 8 illustrates a portion of a transmitting system in which two separate frequencies are fed from two separate sources over two separate feeder lines to one transmission line. In this figure, two pairs of conjugate impedances in accordance with the present invention are employed, each of which serves to block one of the transmission feeder lines with respect to the frequency transmitted over the other feeder line. Fig. 9 represents a pair of conjugate impedances in accordance with the present invention applied to a transmission line and connected so as to serve for draining this line to ground. Fig. 10 illustrates the use of a plurality of pairs of impedances in accordance with the present invention applied to a line which is subjected to three different frequencies. These pairs of impedances are arranged to cause no important change in transmission characteristics with respect to two of the frequencies while causing a desired change with respect to the third frequency. Figs. 11, 12 and 13 illustrate the application to a transmission line of other possible forms of impedances which are not preferred but may be used for any of the purposes of the present invention.

Referring now more particularly to Fig. 1, **101** represents a transmitter station from which waves for frequency F as well as waves of frequency *f* are transmitted over transmission line **102** to radiating antenna **103**. It is assumed that by means of matching device **110** (which may be a transformer or a conventional building-out section) the surge impedance of line **102** has been matched to the characteristic impedance of the antenna **103** for waves of frequency F, as illustrated by the upper curve of Fig. 1. Thus, there will be no standing waves at frequency F when energy is fed from the transmitter station **101** over the line **102** to the antenna **103** as shown by the upper curve of Fig. 1. With respect to frequency *f*, it is assumed that the antenna and line are not matched. Therefore, upon the feeding of waves of this frequency from the transmitter station, a disturbance will be set up as shown in the lower curve of Fig. 1 just above the transmission line. Such a standing wave condition is undesirable both from the standpoint of losses along the transmission line and from the standpoint of maximum efficiency in delivering the energy from the transmitter station to the line. In accordance with the present invention, therefore, a pair of impedances are to be connected to the transmission line at the locations indicated in Fig. 1 by dot and dash lines. The positions at which these impedances must be connected are related to the position of the standing wave pattern which is to be eliminated. Dimension "*s*" in Fig. 1 represents the distance in a forward direction from the dot-dash line which marks the position of the front impedance or section of the conjugate pair to the next peak of the standing current waves to be eliminated. The proportions and spacing of the pair of impedances also depend upon the severeness or intensity of the standing waves to be eliminated. A convenient measure of this intensity is the ratio of the current minimum to the current maximum of the standing waves. Hereinafter this ratio is assumed to be *r*.

Referring now to Fig. 2, the transmitter station **201**, the transmission line **202**, the matching device **210**, and the radiating antenna **203** correspond exactly to the parts **101**, **102**, **110** and **103** of Fig. 1. In Fig. 2, however, two impedances **220** and **221** are shown connected to the transmission line at the locations indicated by the dot-dash lines. In this particular embodiment each of the impedances consists of a section of transmission line (having the same characteristics as transmission line **202**) connected at one end to the transmission line and short-circuited at the other end. The lengths and spacing of these two sections **220** and **221** are determined in accordance with an experimental procedure or a set of mathematical formulae as fully explained below. With respect to waves of frequency F, these two sections **220** and **221** are conjugate. In all those portions of the transmission line which lie outside of these sections no change in the transmission characteristics of the line is produced for waves of frequency F—excepting a change of phase which is often of no importance. As illustrated by the upper curve of Fig. 2, standing waves are produced at frequency F in that part of the transmission line **202** which lies between the sections **220** and **221**. In all other portions of the transmitting line, however, the conditions are the same as before, as shown in Fig. 1; i. e. there are no standing waves to frequency F. With respect to frequency *f*, however, the pair of sections **220**, **221** not only create a new form of standing waves in that portion of the transmission line which lies between them but also cause a desired modification of the standing wave pattern between the rear section **220** and the transmitter station **201**. Forward of front section **221**, the standing wave pattern for frequency *f* (due to the mismatch at frequency *f* of antenna 203 together with matching device 210) is unchanged. Backward from rear section 220 the previously existing standing waves are completely neutralized or eliminated, so that with respect to transmitter station 201 and the rear portions of transmission line 202 the transmission line is perfectly matched to the antenna. It is assumed that the major part of the transmission line 202 lies behind the rear section 220 so that most of this transmission line is free from standing waves.

Fig. 3 illustrates a pair of sections of a different form which may be used for the same purposes as 220 and 221. In Fig. 3 both the rear section 320 and the front section 321 consist of sections of transmission line (having the same characteristics as the main transmission line 302) connected at one end to this main transmission line and open-circuited or insulated at their free ends. For the particular configuration of waves and the particular spacing of sections here assumed for illustration, the lengths of the open-circuited sections 320 and 321 will be somewhat longer than the lengths of the corresponding sections 220 and 221. In some cases, however, it will happen that the lengths of open sections, such as 320 and 321, will be shorter than the lengths of equivalent closed sections, such as 220 and 221.

Fig. 4 represents a pair of sections of which the rear one 420 is of the closed type while the front one 421 is of the open type. Fig. 5, on the other hand, represents an arrangement which is exactly the reverse of Fig. 4; that is, the rear section 520 is of the open type (like 320 and 321) while the front section 521 is of the closed type (like 220 and 221).

For determining the correct dimensions and proportions of any of the sections illustrated in Figs. 2, 3, 4, or 5, a simple empirical measuring procedure may be employed. As illustrated in Fig. 6, a trial source 606 is connected to a test transmission line 602 which is terminated at its far end in a reflectionless terminating resistor 608. The trial source 606 is arranged so that either frequency F or frequency *f* may be generated. The resistor 608 should be adjustable so that it may simulate the surge impedance of the transmission line 602 for either of these frequencies—unless the surge impedances at the two frequencies are so closely the same that a single fixed resistor may be used. Any convenient form of current meter may be employed to indicate the absence of standing waves so as to be sure that the resistor is acting as a proper termination. The transmission line 602 should be exactly equivalent to the transmission line with which the conjugate sections are actually to be used.

A pair of sections 620 and 621 are now slidably connected to the trial transmission line 601. This pair of sections may be of any form, such as the forms illustrated in Figs. 2, 3, 4 and 5. The lengths of each of these sections 620 and 621 should also be readily adjustable. In the case of a closed section, this adjustability may be attained simply by providing a slidable short-circuiting wire for short-circuiting the section at an adjustable point. In case of the open type of section telescopic wire may be used. For this type, however, the adjustment may be most easily performed by employing a section which is known to be too long, and then gradually shortening it by cutting until the desired adjustment is reached. In the case of such open sections, moreover, minor adjustments of length may be made by bending over the ends of the wire.

The trial source is now arranged to generate frequency F and the lengths of the sections as well as the distance between them are adjusted until conjugacy is reached, i. e. until there are no standing waves along the transmission line except between the sections 620 and 621. As will be shown later in connection with the mathematical analysis, only two types of conjugacy will be found, each of which, however, includes an infinite number of adjustments of rear section length with corresponding adjustments of the front section length and the spacing distance between sections. The first such type of conjugacy, "symmetrical conjugacy" requires a spacing between sections which is in general not equal to an integral number of half wave-lengths and must be determined by measurement (or from a formula as explained hereinafter). For this type of conjugacy, however, the impedances of the two sections 620 and 621 should always be identical. In the case of pairs, such as illustrated in Figs. 2 and 3, this means that the lengths of the sections will either be identical or differ by an integral number of half wave-lengths of a wave of frequency F. In the case of sections, such as illustrated in Figs. 4 and 5, the lengths of the front and rear sections will differ by one-quarter wave-length or by an odd number of quarter wave-lengths. This rule will greatly simplify the number of adjustments which need to be made in attaining conjugacy of the symmetrical type.

The second type of conjugacy, "asymmetrical conjugacy", requires that the spacing distance between sections should always be an integral number of half wave-lengths. In this type of conjugacy, the lengths of the two sections will in general be different. For pairs of the type shown in Figs. 2 and 3, the sum of the lengths of the front and rear sections will always be an integral number of half wave-lengths. For pairs of sections of the types illustrated in Figs. 4 and 5, the sum of the front section length plus the rear section length will always be an odd number of quarter wave-lengths. These rules will greatly simplify the making of the necessary adjustments for conjugacy.

After conjugacy has been secured for frequency F, the trial source 606 and the resistor 608 should be altered so that frequency *f* is transmitted over the line 602 and absorbed without reflection at the termination 608. In general, a standing wave pattern will be set up between the trial source 606 and the front section 621. The location as indicated by *s* of the current peaks of these standing waves relative to the front section 621 should be noted as well as the intensity factor *r*. The value of *r* may conveniently be chosen as a tabulating index against which the other quantities, such as the location dimensions, the rear section length *a* or *p*, the front section length *b* or *q*, and the spacing distance *d* may be listed. A complete tabulation of this type covering a sufficient number of values of *r* and the corresponding other quantities to determine quite accurately all practicable proportions for a given pair of frequencies may be readily carried out in a short time.

In applying the results of such measurements to a specific problem such as illustrated in Fig. 1, it is merely necessary to select an intensity factor *r* equal to the intensity factor of the standing waves to be eliminated. Then a pair of sections having the dimensions corresponding to those tabulated under that value of r should be constructed. This pair of sections should be located along the transmission line (102, for example) so that the front section is exactly s units back of a current peak of the standing wave. In other words, the arrangement of the sections relative to the standing waves should be the same along the transmission line 102 as along the trial line 602 when the trial source 606 is taken to correspond with the antenna 103 and the terminating resistor 608 is considered as corresponding to transmitter station 101. As illustrated in Fig. 2, the purpose of the pair of sections is to prevent this wave from extending back of the sections. This will be accomplished if in transferring the set-up determined from Fig. 6 to a transmission line to be corrected as shown in Fig. 1, the front section to be added to Fig. 1 is located the same distance s behind a current maximum (of the standing waves to be stopped in Fig. 1) as the front section 621 was located behind its current maximum in Fig. 6.

Instead of employing the above outlined empirical measurements, the desired dimensions of the pair of sections may be determined by computation from the following formulae in which:

All lengths are expressed in degrees on the basis that 360°=wave-length of ordinary travelling waves along the transmission line. (Distance between peaks of standing waves on this basis=180°.)

Capital letters represent quantities measured with respect to frequency F.

Lower case letters represent quantities measured with respect to frequency f.

A or a=length of "rear section" in degrees (for sections of short-circuited type).

B or b=length of "front section" in degrees (for sections of short-circuited type).

P or p=length of "rear section in degrees (for sections of open-ended type).

Q or q=length of "front section" in degrees (for sections of open-ended type).

D or d=distance between sections in degrees (any types of sections).

F=frequency for which sections are conjugate.

f=frequency for which sections are not conjugate.

H=phase delay (in degrees) caused by conjugate pair of sections (a negative value of H indicates a phase advance).

r=ratio of current minima to current maxima for those standing waves (of frequency f) which are to be kept out of the rear portions of the transmission line by the pair of sections.

s=distance forward from front section to next current peak of those standing waves which are to be kept out of the rear portions of the transmission line by the pair of sections.

X or x=generalized coefficient of rear section (to be found from individual formulae).

Y or y=generalized coefficient of front section to be found from individual formulae).

N=any positive or negative integer. N as used in one formula is not necessarily equal to N as used in another formula.

"s" is determined from:

$$\tan 2s=\frac{\sin x\,[\cos(2d+x+2y)+\sin^2 y\cos(2d+x)+\sin y\cos y\,(\csc x+\sin x)]}{\sin x\,[\sin(2d+x+2y)-\sin^2 y\sin(2d+x)+\sin^2 y\,(\csc x+\sin x)]}$$

as well as from the following rule:

$2s$ is in first quadrant if numerator is − and denominator is −.

$2s$ is in second quadrant if numerator is − and denominator is +.

$2s$ is in third quadrant if numerator is + and denominator is +.

$2s$ is in fourth quadrant if numerator is + and denominator is −.

"r" is determined from the following formula:

$$\left(\frac{1-r}{1+r}\right)^2=\frac{\sin^2 x+\sin^2 y+2\sin x\sin y\cos(2d+x+y)}{1+\sin^2 x\sin^2 y+2\sin x\sin y\cos(2d+x+y)}$$

together with the following rule:

$$\frac{1-r}{1+r}$$

is positive; r is a positive number not greater than unity.

The above formulae and rules apply generally to any types of conjugate impedances. The above formulae relate to the intensity and position of the standing waves for the frequency f at which the sections are not conjugate. The generalized formulae and rules for conjugacy are as follows:

For symmetric conjugacy $X-Y=N$ (180°); tan $D=\cot X=\cot Y$;

$$\tan\frac{H}{2}=\tan X=\tan Y$$

For asymmetric conjugacy $\tan X+\tan Y=0$; $D=N$ (180°); $H=0$.

All the above formulae and rules are in generalized form and employ the coefficients x, y, X, Y. These coefficients depend upon the impedances of the sections for frequencies f and F—x depending upon the impedance of the rear section for frequency f, y depending upon the impedance of the front section for frequency f, X depending upon the impedance of the rear section for frequency F, and Y depending upon the impedance of the front section for frequency F. In general for a front impedance element whose impedances at frequencies F and f are jC and jc respectively and a rear element whose corresponding impedances are jG and jg the coefficients X, Y, x and y are determined by the equations

$$\tan X=-\frac{Z}{2C};\ \tan Y=-\frac{Z}{2G};$$

$$\tan x=-\frac{z}{2c};\ \tan y=-\frac{z}{2g}$$

where Z and z are the surge impedances of the line for frequencies F and f.

In the case of a pair of sections such as illustrated in Fig. 2, the formulae for x, X, y and Y are:

Tan $x=-\frac{1}{2}\cot a$; $\tan y=-\frac{1}{2}\cot b$; $\tan X=-\frac{1}{2}\cot A$; $\tan Y=-\frac{1}{2}\cot B$.

In this case the conjugacy relations become very simple as follows:

For symmetric conjugacy $A-B=N$ (180°); tan $D=-2\tan A=-2\tan B$;

$$\tan\frac{H}{2}=-\frac{1}{2}\cot A=-\frac{1}{2}\cot B$$

For asymmetric conjugacy $A+B=N$ (180°); $D=N$ (180°); $H=0$.

In the case of a pair of sections of the type illutrated in Fig. 3:

Tan $x=\frac{1}{2}$ tan p; tan $y=\frac{1}{2}$ tan q; tan $X=\frac{1}{2}$ tan P; tan $Y=\frac{1}{2}$ tan Q.

In this case the conjugacy formulae become:

For symmetric conjugacy $P-Q=N$ (180°); tan $D=2$ cot $P=2$ cot Q;

$$\tan\frac{H}{2}=\tfrac{1}{2}\tan P=\tfrac{1}{2}\tan Q$$

For asymmetric conjugacy $P+Q=N$ (180°); $D=N$ (180°); $H=0$.

In the case of a pair of sections of the type illustrated in Fig. 4:

Tan $x=-\frac{1}{2}$ cot a; tan $y=-\frac{1}{2}$ tan q; tan $X=-\frac{1}{2}$ cot A; tan $Y=\frac{1}{2}$ tan Q.

In this case the conjugacy formulae become:

For symmetric conjugacy $A-Q=90°+N$ (180°); tan $D=-2$ tan $A=2$ cot Q;

$$\tan\frac{H}{2}=-\tfrac{1}{2}\cot A=\tfrac{1}{2}\tan Q$$

For asymmetric conjugacy $A+Q=90°+N$ (180°); $D=N$ (180°); $H=0$.

Finally, in the case of a pair of sections such as illustrated in Fig. 5:

Tan $x=\frac{1}{2}$ tan p; tan $y=-\frac{1}{2}$ cot b; tan $X=\frac{1}{2}$ tan P; tan $Y=-\frac{1}{2}$ cot B.

In this case the conjugacy relations become:

For symmetric conjugacy $P-B=90°+N$ (180°); tan $D=2$ cot $P=-2$ tan B;

$$\tan\frac{H}{2}=\tfrac{1}{2}\tan P=-\tfrac{1}{2}\cot B$$

For asymmetric conjugacy $P+B=90°+N$ (180°); $D=N$ (180°); $H=0$.

In employing the mathematical formulae above given, the known factors will usually be the frequencies f and F and the intensity factor r. In such a case, it is most convenient to solve the problem graphically. For computing each point, a length of the rear section (A or P) may be arbitrarily assumed. Then the length of the front section (B or Q) and the spacing distance between the sections (D) may be readily found from the simple conjugacy relations. Any number of such quantities may theoretically be found which will satify the conjugacy conditions, but only a small number of these lengths and spacing distances are of practical size. Then, from these values A or P, B or Q, D the corresponding values a or p, b or q, d may be found. These latter quantities represent the same distances as the former quantities but are expressed in terms of the wave-length of the non-conjugate wave instead of the wave-length of the conjugate wave. From these latter values, the quantities r and s may be readily computed and all these quantities are then plotted or tabulated against r. If the computations are intended for use with only one specific problem, it will be sufficient to compute widely separated points until the approximate desired value of r is approached and then to compute the points closer together in well known manner. Finally, the set of quantities corresponding to the desired r are selected either from the graphical curves or the tabulations. A pair of sections having these tabulated dimensions are then constructed and connected to the tranmission line with a spacing distance d as also shown by the tabulations. The location of this whole pair of impedances relative to the standing wave which is to be neutralized or blocked is determined by the tabulated value s as illustrated in Figs. 1 and 2. After neutralization of the pair of sections, a final trimming adjustment may be made by slightly varying merely the length of one of the sections or, if greater accuracy is desired, by alternately varying the lengths of the sections and the spacing distance d.

Fig. 7 illustrates the use of a pair of conjugate sections for shifting the phase of a wave of frequency F without altering any other characteristics of its transmission. In this figure, **701** is a transmitting station over which waves of frequency F are transmitted over lines **702**, **707** and **757** to the radiating antennae **703** and **753**. It is assumed that by means of matching devices **710** and **760** the impedances of the antennae are matched to the surge impedance of the transmission line and that the surge impedance of the main portion of single transmission line **702** is matched by means of device **712** to the surge impedance of the two sections **707** and **757** in parallel. It is now desirable for the purpose of adjusting the directional characteristics of the pair of antennae to adjust the relative phase of the radiation from these antennae without disturbing the impedance matching which has previously been attained.

This object may be achieved by the use of a pair of conjugate impedances **720** and **721**. This pair of impedances is shown as applied to the longer branch line **757** but might equally well be applied to the shorter branch line **707**. This pair of impedances also has been shown as consisting of two closed sections of the type illustrated in Figure 2, but any of the types shown in Figs. 3, 4 and 5 might equally well be used. The lengths of the sections **720** and **721** and the spacing distance between them are adjusted so that the sections will be conjugate with respect to the frequency F either by empirical measurement or by the formulae for conjugacy given above. Subject to the relationship thus imposed the proportions of the conjugate pair are now varied (as for example by altering the length of the rear section **720** and then correspondingly altering the length of the front section **721** and the spacing distance between sections) until the desired phase relationship is attained. If it is desired to compute the proportions necessary for a given amount of phase shift, this may be done from the formulae for H given above. It will be noted that symmetric conjugacy is the only type which may be here used, since the phase shift for asymmetric conjugacy is always zero.

Figure 8 shows the application of conjugate pairs to branch feeder lines for the purpose of blocking these feeder lines with respect to certain undesired frequencies. In this figure, transmitter station **801** is adapted to supply waves of frequency f (whose wave-length is w) over feeder transmission line **809** to the main transmission line **802** while transmitter station **851** is adapted to transmit waves of frequency F (whose wave-length is W) over feeder transmission line **859** to main transmission line **802**. It is undesirable to permit the waves of frequency f to back up through feeder transmission line **859** into the transmitter station **851**. Similarly it is undesirable to permit waves of frequency F to back up over feeder transmission line **809** into transmitter station **801**. Furthermore, it is assumed that the surge impedance of feeder transmission line **809** is exactly matched to the surge impedance of the main transmission line **802** and similarly with regard to feeder transmission line 859 and main transmission line 802. It is therefore desirable not only to block each feeder transmission line with respect to the waves transmitted over the other feeder transmission line, but even further than this it is desirable to perform this blocking in such a way that a blocked-off feeder transmission line apparently does not exist at all so far as the waves for which it is blocked are concerned. In other words not only must feeder line 859 be rendered impassable to waves of frequency *f* but the transmission conditions for the waves of frequency *f* should be exactly as if feeder line 859 did not exist at all. The corresponding should also be true with respect to feeder line 809 and waves of frequency F.

One method of attaining these objects by the use of the present invention is illustrated in Fig. 8. A pair of impedances 870 and 871 which for the purpose of illustration are assumed to be of the type shown in Fig. 2 are applied to feeder line 859. With respect to frequency F which must be transmitted over this feeder line 859 impedances 870 and 871 are conjugate and therefore have no effect (except possibly an unimportant phase shift if symmetric conjugacy is used). These impedances, however, are so adjusted that with respect to frequency *f* they will act as a direct short-circuit. With reference to Fig. 6 this means that the standing current waves produced by these impedances will be completely standing waves with no travelling component, or in other words, that the minima of these waves will be zero. With respect to the formulae this means that the factor *r*, which represents the ratio of the minimum current to the maximum current, will be zero. As a result of this adjustment the pair of impedances 870 and 871 will be—so far as frequency *f* is concerned—exactly the same as a short-circuit located at the position of impedance 871. The location of the pair of impedances along the feeder line 859 should now be adjusted so that the distance *k* between section 871 and the junction of the feeder lines is exactly 90° plus N (180°). The distance *k* is understood to be measured with respect to the wave-length *w* of the waves of frequency *f*. By this adjustment feeder line 859 is not only blocked with respect to waves of frequency *f* but is virtually caused to be non-existent for these waves, since this feeder line with its pair of sections 870 and 871 is now equivalent for frequency *f* to a section of line 90° (or 270°, 450°, etc.) in length short-circuited at its far end. On feeder line 809 a pair of conjugate impedances 820 and 821 are similarly applied. These impedances 820 and 821, however, are conjugate with respect to frequency *f* and are proportioned so as to be equivalent to a short-circuit with respect to waves of frequency F. In a manner similar to that above described this adjustment results not only in blocking feeder line 809 with respect to frequency F but also in virtually causing this feeder line 809 to be non-existent for the waves of frequency F.

The main transmission line 802 may now transmit the waves of both frequencies to any suitable type of antenna; or if desired these waves may be separated from each other and diverted respectively into two separate feeder lines by an arrangement exactly similar to that just described for bringing these waves together.

Fig. 9 illustrates a pair of conjugate sections 920 and 921 of the type shown in Fig. 2 which are used for any of the purposes previously described and simultaneously are adapted to serve for grounding the transmission line 902. Grounding is thus attained without in any way disturbing the transmission along the line at the frequency for which the pair of sections are conjugate. A special pair of sections may, if desired, be provided on a transmission line merely for the purpose of grounding it. Any of the types of pairs shown in Figs. 2, 4 or 5 may be used. The type shown in Figs. 4 and 5 will only provide one grounding point along the line.

Fig. 10 illustrates the use of two pairs of conjugate sections 1020 and 1021 and 1070 and 1071 for producing a desired disturbance at one given frequency *f'* while being conjugate at two other frequencies F and *f*. This construction may be derived as folllows:

A measuring set-up similar to that of Fig. 6 is used, the trial source and termination being suitable for three frequencies. Two pairs of adjustable sections are connected as shown in Fig. 10.

The first pair comprising sections 1020 and 1021 is (throughout the adjustments to be described) constantly maintained in such proportion as always to be conjugate at frequency F. The second pair 1070 and 1071 is also constantly kept conjugate at this same frequency. Subject to these limitations any one dimension of either one of these pairs is arbitrarily fixed (thus determining all the dimensions of that pair) while one dimension of the other pair is progressively altered (with corresponding alterations of the remaining dimensions of this other pair) until the total effect of both pairs with respect to frequency *f* is zero; i. e. until the pair of pairs is conjugate at frequency *f*. The resulting intensity factor *r'* of the standing current waves produced by the pair of pairs at the third frequency *f'* is now noted and tabulated with all the corresponding data.

It will be noted that the above adjustments were made with one arbitrarily chosen dimension for one of the pairs. By selecting different values for this arbitrarily selected dimension the total effect of the two pairs of sections on the waves of frequency *f'* may be adjusted to any suitable value while the total effect of the two pairs on both other frequencies *f* and F are continually kept at zero.

By a similar method and by the use of a greater number of sections this same principle may be extended to four or five waves, etc.

Figs. 11, 12 and 13 illustrate the use of other forms of impedance which may be desirable in certain cases. In all the previously illustrated embodiments the preferred form of impedance is comprised of sections of transmission line, these sections being either open-circuited or short-circuited at the free end. These sections of transmission line have been assumed to be of the same characteristics as the transmission line to which the sections are attached. Although such a construction has many advantages and is particularly simple from the standpoint of computation and design, it may be desirable in some cases to use impedances of other forms. Fig. 11 illustrates, for example, the use of two impedances 1120 and 1121 each of which is constituted by an ordinary helically wound inductance. Fig. 12 shows the use of two capacitances 1220 and 1221 which may be air condensers of any well known type but which should preferably be suitable for open-air mounting. Fig. 13 illustrates the use of two special impedances 1320 and 1321 constructed of a plurality of sections of transmission line branched together as shown in the drawings. While each of these impedances is illustrated as comprising a closed section of transmission line having another closed section branching from it, it is also possible to employ an open section having an open section branching from it. Or a closed section with an open branch, an open section with a closed branch or in general any type of section with any type of branch may be used. Impedances of the type illustrated in Fig. 13 are more fully described in my copending application Serial No. 12,451, filed March 22, 1935.

Any of the impedances shown in Figs. 11, 12 or 13 may be combined with any other type of impedance to form a conjugate pair since it is not essential that both impedances of a pair be of the same construction.

For computing the spacing distance (D or d) phase shift H, intensity ratio r and location dimension s, all the same formulae given above may be used no matter what forms of elements are chosen. One very simple way to perform computations with elements which are not simple sections such as illustrated in Figs. 2, 3, 4 and 5 is to express the impedance in the form of equivalent lengths of some simple form of section and then to carry out the computation just as if such simple sections were involved. For example, if a pair of inductances are to be used the impedances of these may conveniently be expressed, not in henries or ohms, but by the length of an equivalent short-circuited section, for instance, "75° at frequency f". It will be understood, of course, that such equivalency will in general hold only for one frequency. If preferred, however, the impedance values themselves may be used for determining x and y or X and Y by means of the general impedance formulae.

For nearly all practical purposes the impedances used will preferably be practically pure reactances so that the resistive component may be neglected. In fact, it has hitherto been assumed in all the previous discussion that the impedances to be used would be of this type. In case complex impedances must be handled, however, the formulae given above can still be employed by merely considering that C and G are complex numbers such that jC and jG represent the impedances of the rear and front elements respectively. For most purposes, however, such involved calculations are wholly unnecessary.

In applying all the formulae above described to the case of simple sections of transmission line such as illustrated in Figs. 2, 3, 4 and 5 a small end-correction will be necessary. The value of this end-correction will depend upon the characteristics of the transmission line used for the sections as well as on the type of insulators and the shape of the short-circuiting portion in the case of closed sections. In all practical cases, however, this end-correction may be readily determined for a given type of section and will be practically constant. Thus it will be found that for any given type of section the real physical length to be used will differ from the computed length by a small almost constant amount. Ordinarily the magnitude of this correction will be of the order of a few inches for the types of construction in general use with wave-lengths of 10 to 30 meters.

In the interests of clarity and brevity the above description has been confined to transmission lines joining "transmitter stations" to "wave radiating antennae". The structures described are, of course, much more generally applicable. The "transmitter stations" should be understood to be wave sources of any type (such as collecting antennae, wave carrying lines bearing incoming energy, wave generators etc.). Similarly the radiating antennae should be understood to be wave receiving devices of any type (such as detectors, receiving stations, wave carrying lines bearing outgoing energy, etc.).

Furthermore, it is well known that transmitting and receiving antenna and transmission systems are mutually interchangeable. It is is therefore believed unnecessary to separately describe and illustrate the converse equivalent of each embodiment. The radiating antennae may be used as collecting antennae the "transmitter stations" being merely replaced by "receiving stations" and the transmission arrangements in between being unchanged. Or generally the wave sources may be replaced by wave receiving devices of the same impedance and the wave receiving devices by wave sources of the same impedance. Thus the structure for matching the impedance of a generator to the surge impedance of a line, for example, is clearly described and illustrated in connection with Figs. 1 to 6 if the device labeled "radiating antenna" be understood to be a wave generator and the equipment labeled "transmitter station" be understood to be a wave receiving equipment. Similarly Fig. 7 and its appertaining description if conversely interpreted discloses a structure for adjusting the relative phases of two wave sources connected to one transmission line. Similarly also Fig. 8 and its description can be taken as explaining a structure for separating two waves which arrive over one transmission line and are to be diverted onto two separate branch lines.

Although the invention has been described in connection with simple two wire transmission lines, it can be carried out in conjunction with coaxial lines. In such a case sections of coaxial line would preferably be used for the conjugate impedances so as to gain the same advantages as when sections of simple two wire are used as the impedances in conjunction with a simple two wire transmission line. It is possible, however, to use simple two wire sections on a coaxial transmission line or even to use lumped impedances on coaxial lines as above described in conjunction with simple two wire transmission lines.

What I claim is:

1. A transmission adjusting arrangement for a line of surge impedance Z carrying waves of a predetermined frequency, which comprises in conjunction with said line a pair of elements having for those waves reactive impedances of jC and jG respectively, said element being connected in shunt to said line at two points which are an integral number of half wave lengths apart, the impedance values being so related that

$$\frac{Z}{2C}+\frac{Z}{2G}=0$$

2. A transmission adjusting arrangement for a line whose surge impedance is Z and which is adapted for carrying waves of predetermined frequency, which comprises in conjunction with said line a pair of elements which have for said waves equal impedances whose value is jC, said elements being connected in shunt to said line at two points D degrees apart such that

$$\tan D=-\frac{2C}{Z}$$

3. The method of adjusting a plurality of trans-

mission modifying elements each of which is directly connected to a transmission line over which at least two predetermined frequencies are carried comprising first adjusting one or more of said elements to cause a desired modification at a first one of said frequencies, then adjusting at least two others of said elements in such a manner that the transmission at said first frequency remains continually unaffected by said other elements while the transmission at a second one of said frequencies is varied by said other elements, and continuing said latter adjustment until the resulting transmission at said second frequency is modified to a predetermined point.

4. A transmission system comprising a translating device, a translating apparatus, a line connected between said device and said apparatus the surge impedance of said line differing from the impedance of the device, said line serving to carry waves of at least two predetermined frequencies between said device and said apparatus, a pair of sections of transmission line having the same characteristics as said line, one end of each of said sections being connected to said line, the length of each of said sections and the distance between their points of connection to said line being so related that for waves of one of said frequencies the standing wave pattern along the line outside of said points of connection is the same as if said sections were not connected, whereas for waves of the other of said frequencies all standing waves between said apparatus and the section nearest thereto are substantially suppressed.

5. A transmission system comprising a translating device, a translating apparatus, a line connected between said device and said apparatus the surge impedance of said line differing from the impedance of the device, said line serving to carry waves of at least two predetermined frequencies between said device and said apparatus, a pair of sections of transmission line having the same character as said line one end of each of said sections being connected to said line, the length of each of said sections and the distance between their points of connection to said line being so related that for waves of one of said frequencies the combined impedance of said device, said pair of sections and those portions of the line interconnecting said device and sections is for one of said frequencies equal to the surge impedance of said line, whereas for the other of said frequencies the corresponding combined impedance is the same as if said sections were not connected.

6. A transmission system comprising a source of waves of at least two predetermined frequencies, an apparatus to which said waves are to be transmitted, a transmission line interconnecting said source and said apparatus, the surge impedance of said line differing from the input impedance of said apparatus, a pair of impedance elements connected to said line at two separate points between said source and said apparatus, the impedances of said elements and the distance between said points being so related that waves of one of said frequencies are transmitted from said source to said apparatus in essentially the same manner as if said impedances were not connected, whereas the transmission of waves of the other of said frequencies is altered by the presence of said impedances whereby waves of said other frequency are transmitted from that section of the line between the source and the nearest impedance element into that section of the line to which the impedance elements and the apparatus are connected without reflection.

7. A transmission system comprising a source of waves of at least two predetermined frequencies, an apparatus to which said waves are to be transmitted, a transmission line interconnecting said source and said apparatus, the surge impedance of said line being different from the impedance of said apparatus, a plurality of impedances connected to said line at separate points between said source and said apparatus, the values of said impedances and the spacing between them being such that the waves of one of said frequencies are transmitted along said line with the same attenuations and reflections at all points outside of said impedances as if said impedances were not present, whereas the transmission of waves of another of said frequencies is altered by reflections at said impedances so that the resulting total reflection of the waves of said other frequency toward said source is zero.

8. A transmission system comprising a source of waves of at least two predetermined frequencies, an apparatus for receiving said waves, a transmission line interconnecting said source and said apparatus, the surge impedance of said line being different from the impedance of said source, a plurality of impedances connected at separate points along said line between said source and said apparatus, the values of said impedances and the spacing between them being so related that the total apparent impedance of said source, together with said impedances and those portions of the line interconnecting said source and said impedances is equivalent for one of said frequencies to the surge impedance of said line, whereas for the other of said frequencies the corresponding total apparent impedance is equivalent simply to the impedance of the source as viewed through that portion of the transmission line which interconnects the source and the impedances.

9. A transmission system comprising a transmission line adapted to carry waves of a predetermined frequency, a plurality of impedance elements connected across said line at separate positions, the impedances of said elements and their spacing along said line being so inter-related that the combined reflections caused by said elements at every point along the line outside of all of them is zero for waves of said frequency, and a connection from a point of one of said elements to ground.

10. A transmission system comprising a transmission line adapted to carry waves of a predetermined frequency, a plurality of impedance elements connected across said line at separate positions, the impedances of said elements and their spacing along said line being so interrelated that the combined reflections caused by said elements at every point along the line outside of all of them is zero for waves of said frequency, and a connection from the mid-point of one of said elements to ground.

11. A transmission adjusting arrangement for transmission lines and the like over which at least three frequencies are transmitted comprising at least three impedance elements connected to the line at points separate from one another, the impedances of each of said elements and the separation between their points of connection to the line being so related that waves of at least two of said frequencies are transmitted with the

same reflections and attenuations at every point along the line outside of said elements as if said elements were not connected to said line, whereas the total reflection undergone by waves of another of said frequencies is altered by the presence of said elements.

12. A transmission system comprising a transmission line adapted to carry waves of at least two predetermined frequencies, two branch lines connected to said first named line and each adapted to carry waves of one of said frequencies, a pair of impedance elements connected to each of said branch lines, the spacing between the junction of the branch lines and the impedance element nearest thereto on one of the branch lines being an integral number of quarter wave lengths with respect to the frequency adapted to be carried by the other branch line and the relation between the spacing and impedance values of the elements on said first named branch line being such that these elements produce no essential alteration in the waves transmitted along said first named branch line, while simultaneously being such that these elements act like a short circuit for waves of the frequency carried by said other branch line.

13. A transmission adjusting arrangement for transmission lines and the like carrying a plurality of frequencies, comprising a set of impedance elements connected to the line at spaced points, the spacing between said elements being proportioned with respect to the impedances of said elements so that with respect to waves of at least one of said frequencies the backwardly traveling waves produced by partial reflection of said waves at the first of said impedances encountered by said waves are equal in amplitude and opposite in phase to the backwardly traveling waves produced by reflection at the second of said impedances of that part of said waves passing through said first impedance, whereby at said one of said frequencies the standing-wave pattern on the line outside said elements is the same as if said elements were not connected.

14. A transmission adjusting arrangement for transmission lines and the like carrying a plurality of frequencies comprising a set of impedance elements connected to the line at spaced points, the spacing between said elements being proportioned with respect to the impedances of each of said elements so that with respect to waves of at least one of said frequencies the backwardly traveling waves produced by partial reflection of said waves at the first of said impedances encountered by said waves are equal in amplitude and opposite in phase to the backwardly traveling waves produced by reflection at the second of said impedances of that part of said waves passing through said first impedance whereby at said one of said frequencies the total reflection produced by said set of elements is zero.

15. A transmission adjusting arrangement for transmission lines and the like over which at least one predetermined frequency is transmitted comprising a set of impedance elements connected to the line at spaced points, the spacing between said elements being proportioned with respect to the impedance of each of said elements so that with respect to waves of said frequency, the backwardly traveling waves produced by partial reflection of said waves at the first of said impedances encountered by said waves are equal in amplitude and opposite in phase to the backwardly traveling waves produced by reflection at the second of said impedances of that part of said waves passing through said first impedance, whereby at said one of said frequencies the standing-wave pattern on the line outside said elements is the same as if said elements were not connected.

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