March 21, 1944. R. D. KIRKLAND 2,344,884

WAVE TRANSMISSION SYSTEM

Filed Feb. 6, 1942

FIG.1.

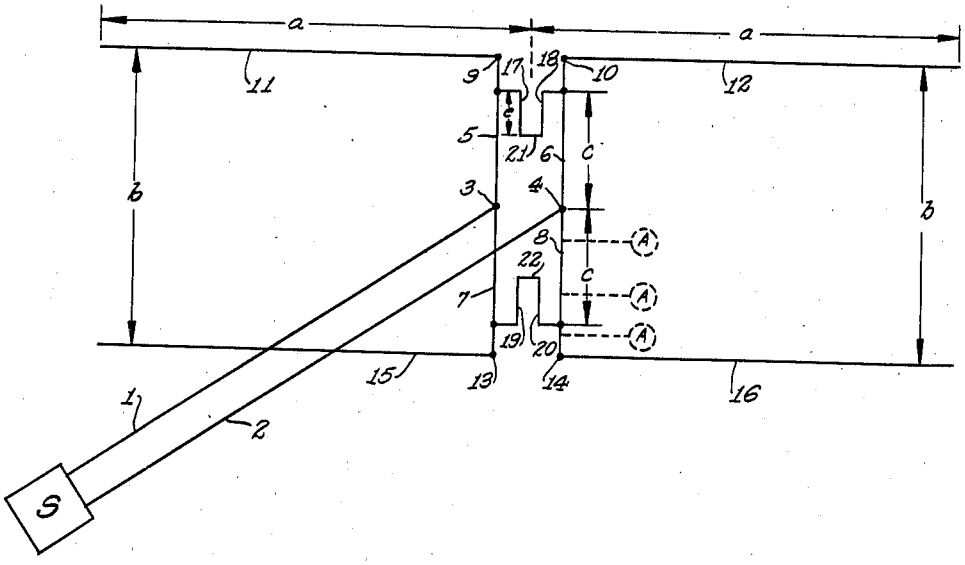
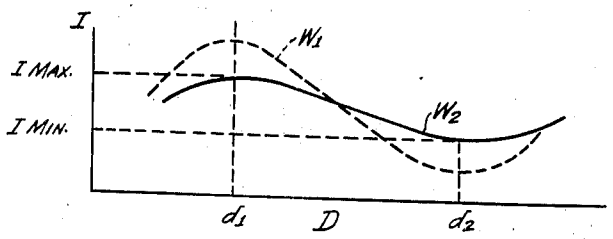


FIG.2.



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WAVE TRANSMISSION SYSTEM

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3 Claims. (Cl. 250—33)

This invention relates to wave transmission lines, and particularly to lines for transmitting wave energy to branch lines leading to wave antennae.

The object of the invention is to prevent wave reflections in a transmission line supplying energy to branch lines which contain standing waves.

It sometimes occurs that a transmission line is terminated by a pair of branch lines joined together at the end of the transmission line. Such a condition may exist, for example, when a pair of wave antennae are to be supplied with energy from the transmission line. It is well known that in order to prevent undesirable wave reflections in the transmission line, it should be terminated in an impedance equal to its surge impedance. But if the branch lines to which the transmission line is connected do not provide the required surge impedance, as for example when supplying antennae, they do not prevent the reflections. I have found that if the standing waves in the branch lines be reduced so that the ratio of the maximum to the minimum standing wave current has a definite value which depends on the relationship of the surge impedance of the branch lines to the surge impedance of the transmission line, there will be no substantial reflections in the transmission line. In the usual case, wherein the branch lines have the same surge impedance as the transmission line, I have found that the proper ratio of maximum to minimum standing wave current is two-to-one. In accordance with my invention, there are provided building-out sections proportioned and connected at the proper points of the branch lines to provide the desired ratio of maximum to minimum standing wave current in these connecting lines, and a consequent substantial absence of wave reflections in the main transmission line.

This invention will be understood from the following detailed description of a preferred embodiment and the accompanying drawing, in which

Fig. 1 illustrates a diagram of an antenna array supplied by lines according to this invention; and

Fig. 2 is a graph showing a standing wave form obtained in the practice of this invention.

Referring to Fig. 1, wave energy is transmitted from a source S along a transmission line composed of conductors 1 and 2, which may be parallel conductors as shown; or, if desired, the well-known coaxial form of line might be used if provision be made for transforming from its unbalanced character to a balanced character. The other end of the transmission line is connected at junction 3, 4, to respective branch lines 5, 6, and 7, 8. Each of the branch lines is terminated in a load, which in the illustrated system is a wave antenna. The branch 5, 6 is connected at 9, 10 by antenna conductors 11, 12, and branch 7, 8 is connected at 13, 14 to antenna 15, 16. Ordinarily conductors 5 and 7, and likewise, 6 and 8, are conductors placed substantially perpendicular to conductors 1, 2, and antenna 15, 16 is placed below and parallel to antenna 11, 12. The conductors 5, 7 and 6, 8, when supplying an antenna as shown, are preferably placed quite close together, for example, twelve inches apart, so that their separation is only a small fraction of a wavelength, thereby making only a small separation at the middle of each of the two antennae 11, 12 and 15, 16.

The invention is not necessarily limited to any particular dimensions of a load or antenna array, but dimensions which have been found satisfactory in an antenna curtain of the type illustrated are: dimension a equal to 0.65λ and dimensions b equal to 0.6λ where λ is the length of the wave to be used.

When the wave energy is supplied by the transmission line 1, 2, standing waves are set up in the antenna conductors in a well-known manner to produce the required electromagnetic wave radiation. The conductors 5, 6 act as two branch lines joined at the end of the main transmission line 1, 2 for connecting the transmission line with the respective antenna conductors. For a spacing of 0.6λ between the upper and lower conductors, each branch line will be 0.3λ in length, and there will be standing waves set up in conductors 5, 6 and 7, 8 of these branch lines. It is desired that these standing waves be excluded from the main transmission line 1, 2, which would require that the impedance at terminals 3, 4 of the transmission line be made equal to the surge impedance of that line. As the impedance of the antenna array and its branch lines will not ordinarily be equal to the surge impedance, wave reflections will occur which will produce the undesired standing waves in the transmission line.

In order to eliminate the standing waves in the transmission line 1, 2, the impedance due to two branch lines at the junction 3, 4, must be made equal to the surge impedance of line 1, 2. To accomplish this there must be left in each branch line a standing wave, of a definite ratio of maximum to minimum current in the wave. I have found that in the ordinary case, wherein the surge impedance of the main transmission lines and branch lines are equal the required ratio of maximum to minimum standing wave current is two to one. I have discovered that the desired amplitude of standing wave can be obtained by connecting a reactance of a proper value to annul sufficient of the branch line reactance at a point of each branch line where the resistance is of the right value, to leave the desired standing wave. I accomplish the desired correction by connecting building-out lines across each branch

line. These building-out lines may be composed of parallel conductors 17, 18, for one line, and 19, 20, for the other line. The conductors may be made of the same diameter as the conductors of the branch lines and are preferably, although not necessarily, coplanar with conductors 5, 6 and 7, 8. The building-out lines may be closed-ended as shown at 21 and 22, respectively, although they might in some cases be left open-ended if desired.

The effect of the use of the building-out lines of the standing wave is illustrated in Fig. 2, wherein the abscissa D represents distance along the branch line between the junction 3, 4 and 9, 10 (or 13, 14) and the ordinate I represents the standing wave current. The curve W_1 illustrates the form of the standing wave in the absence of the building-out sections showing that the maximum standing wave current in the branch line, which will exist at some point d_1, is much greater than the minimum standing wave current which will exist at some other point d_2. When the building-out sections are connected, this standing wave form of current is modified, and by connecting them at the proper places, the ratio of maximum (I max.) to minimum (I min.) standing wave current may be reduced to its desired value, as shown by the curve W_2.

The manner of proportioning and locating the building-out lines according to this invention will become apparent from the following manner of locating and proportioning them in the system shown, which is given as an example: The impedance of each branch line at its point of connection with the load (in this case the antenna) may be ascertained by measurement; and such measurements will give the impedance at points 9, 10 and 13, 14, respectively. From the values it will be possible to ascertain the magnitude of the resistance R and reactance X at various points along each of the branch lines 5, 6 and 7, 8, prior to the connection of any building-out section; and for convenience, the values may be plotted against distance along the branch lines to give smooth curves of the variations. In order to eliminate standing waves on the transmission line 1, 2, the impedance presented by the branch lines at junction 3, 4 must be made equal to the surge impedance Zo of the transmission line. In the example shown, the characteristic impedances of the transmission line and the two branch lines are assumed to be the same, as this is the most ordinary situation. If these characteristic impedances are, for example, five hundred ohms each, the impedance of each branch line must appear as one thousand ohms resistance, and without reactance, at the junction. Computations can then be made in a well-known manner to compute the resistance and reactance components which each branch line must have at various points along its length in order that its impedance, appearing at the junction 3, 4, shall be 2Zo, that is, $1000+jo$ in the present example. For convenience, these values of the required resistance and reactance may be plotted against distance along the branch lines on the same sheet as the actual values of resistance and reactance are plotted. At some point the required resistance will be found equal to the actual resistance there, and this is the point at which the building-out section should be connected. This point on each branch line is shown in Fig. 1 at the distance C from the junction.

It remains to proportion the building-out section, or corrective impedance, to have the proper reactance to cancel some of the reactance appearing at the points of connection of the building-out section. The building-out section should have a reactance equal to the difference between the required reactance at that point and the actual reactance. For example, if the actual reactance of the branch line at the connection point is found to be of a higher capacitive value than the capacitive value required there, the building-out section should be proportioned to introduce an inductive reactance of the value sufficient to reduce the actual capacitive value down to the required value. Knowing the desired reactance the length c of the building-out line required to produce it can readily be ascertained in a well-known manner. Since some reactance is left in each branch line there will remain therein, standing waves. In the example just given wherein the characteristic impedance of all the lines are the same, the required ratio of maximum (I max.) to minimum (I min.) standing wave current in each branch line is

$$\frac{I \text{ max.}}{I \text{ min.}}=2$$

Although the proper dimensions and location of the building-out sections are susceptible of accurate calculation, it is possible to arrive at the correct place of connection even if it had not been at first quite accurately placed owing to slight discontinuities or irregularities in the installation. This may be done by trying out the correcting impedance at different positions along the branch line until the desired standing wave ratio is produced. The proper points for connecting the building-out sections might be ascertained, for example, by the use of an ammeter or voltmeter which may be placed at different points along the connecting line 5, 6, or 7, 8. The most convenient ammeter or voltmeter to use is a type which does not require the line to be broken to take the reading, but which needs only to be coupled to one of the line conductors, and may thus readily be moved along the line to take meter readings at several points. This method of reading is indicated in Fig. 1 by meter A shown by the dotted circles and shown connected at points of conductor 8. When the connection from this meter is moved along conductor 8 to other positions, as shown, the meter readings will change in the general manner of the standing wave current curves shown in Fig. 2, so that both the maximum and the minimum readings may be readily ascertained on the meter for any point of connection of the building-out section. If it be found that the ratio

$$\frac{I \text{ max.}}{I \text{ min.}}$$

is not the desired value when the building-out sections are first connected, their points of connection may be moved to a different place along conductors 5, 6, and 7, 8, and the ratio

$$\frac{I \text{ max.}}{I \text{ min.}}$$

again determined by running the meter along the conductor. In this way the proper points of connection of the building-out sections can easily be established.

If more convenient, the meter may be moved along the transmission line 1, 2, instead of along the branch line. The position of the building-out sections for which there is the least or no change in meter reading along the line 1, 2, is

the correct position. No change of meter reading would indicate the perfect condition of no standing waves in the transmission line, and the proper standing wave ratio in the branch line.

Although the example given above has been particularly applied to a closed-ended, building-out section giving an inductive correcting reactance, it will be understood that there may be some conditions under which an open-ended building-out section might be used, as where a capacitive correcting reactance is desired. Such capacitive building-out lines would be connected to places where the branch line is inductive. When the branch lines are used to feed antenna arrays of the type shown in the example, an inductive section of the line to which the building-out section may be connected is not so likely to be present as a suitable capacitive section of the branch line, as the branch line will usually be a capacitive reactance extending from the antenna practically to the junction with the transmission line 1, 2.

The building-out sections are coplanar with the branch line, this being a convenient form wherein the building-out line may readily be fastened to the branch line since the conductors are parallel.

The invention is not necessarily limited to the use of branch lines of the same surge impedance as the transmission line, wherein the desired standing wave ratio in the branch lines is two-to-one, although that is the most common situation. If the surge impedances of the branch lines are different from the transmission line, the standing wave ratio needed in the branch lines to prevent wave reflections at their junction with the main line, will be somewhat different from two-to-one; but the required locations and dimensions of the building-out sections can be calculated from knowledge of the impedance of the branch lines, just as in the above example.

What is claimed is:

1. In a wave transmission system, a transmission line, a pair of branch lines in which they are created standing waves, joined to the end of said transmission line, each of said lines having the same surge impedance, and a corrective impedance connected across each of said branch lines at a place which causes the ratio of the maximum to the minimum standing wave current in each branch line to become substantially two-to-one, said corrective impedance comprising conductors lying in the same plane as and between the conductors of the branch line to which it is connected.

2. In a system for transmitting and radiating electromagnetic waves, an antenna array comprising two parallel antenna conductors, each parted at the middle, a connecting line comprising two conductors extendiing parallel to each other between the respective parted ends of the two antenna conductors, a transmission line connected to the middle of said connecting line for supplying wave energy which produces standing waves in the antenna and connecting line, said transmission line and connecting line having the same surge impedance, and a pair of building-out lines connected across said connecting line, one on each side of the junction with said transmission line, each of said building-out lines comprising a pair of parallel conductors lying in the same plane as and between the conductors of said connecting line, the proportions and points of connecting of said building-out lines being fixed to cause the ratio of the maximum to the minimum standing wave current in the connecting line to become substantially two-to-one.

3. A system according to claim 2, in which the conductors of the connecting line and the respective building-out lines parallel therewith are equally spaced in the plane.

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