April 25, 1939.   S. A. SCHELKUNOFF   2,155,508

WAVE GUIDE IMPEDANCE ELEMENT AND NETWORK

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FIG. 1

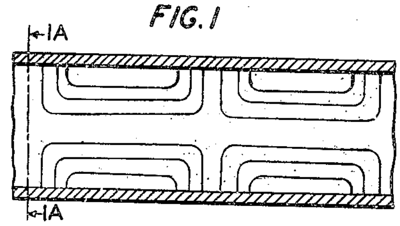

FIG. 1A

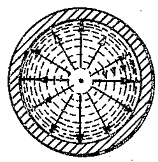

FIG. 5

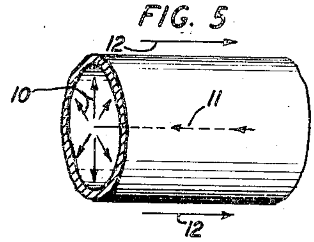

FIG. 2

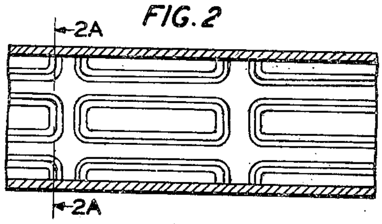

FIG. 2A

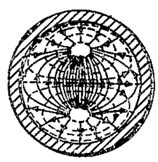

FIG. 5A

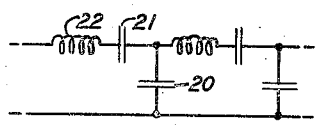

FIG. 3

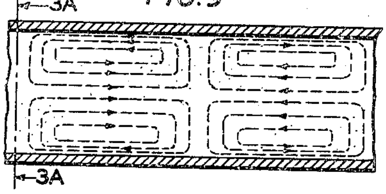

FIG. 3A

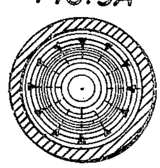

FIG. 6

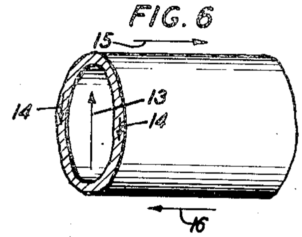

FIG. 4

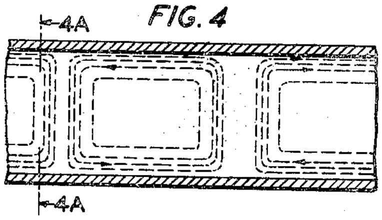

FIG. 4A

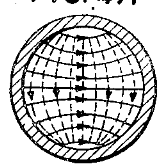

FIG. 6A

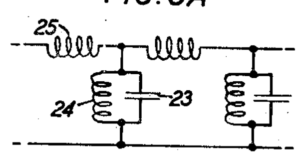

FIG. 7

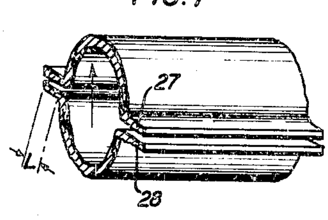

FIG. 7A

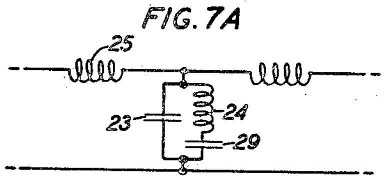

FIG. 8

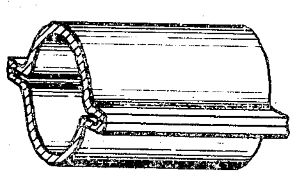

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FIG. 9

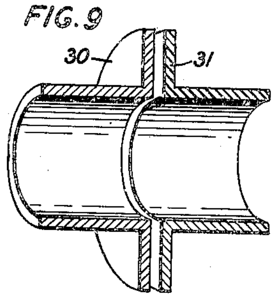


FIG. 10

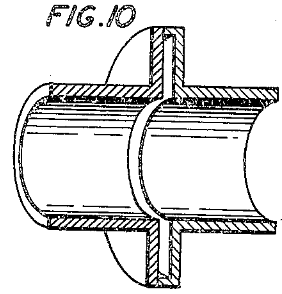


FIG. 10A

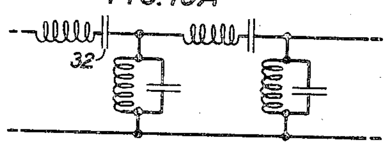


FIG. 11

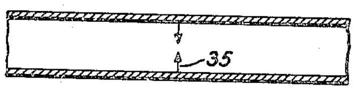


FIG. 12

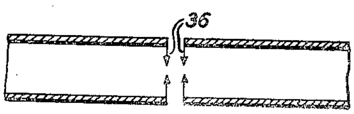


FIG. 13

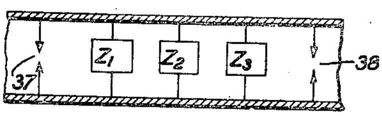


FIG. 14

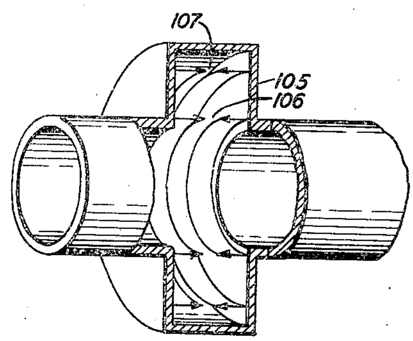


FIG. 14A

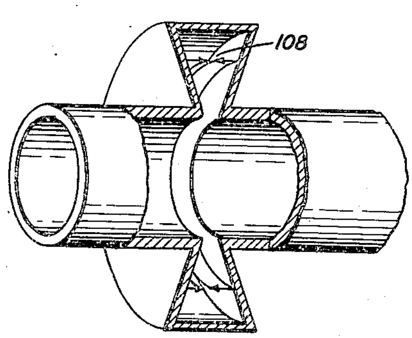


FIG. 15

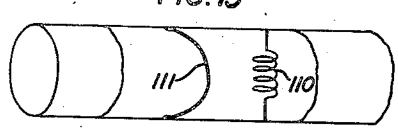
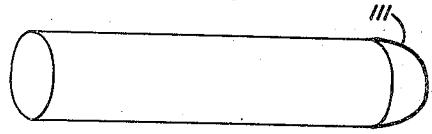


FIG. 16



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Patented Apr. 25, 1939

2,155,508

UNITED STATES PATENT OFFICE

2,155,508

WAVE GUIDE IMPEDANCE ELEMENT AND NETWORK

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Application December 4, 1936, Serial No. 114,129

18 Claims. (Cl. 178—44)

This invention relates to guided electromagnetic wave systems and more particularly to guided wave systems of the kind disclosed in my copending application for Letters Patent Serial No. 56,959 filed December 31, 1935.

One object of the present invention is to introduce either distributed or lumped capacitive or inductive reactances in such a guided wave system.

Another object is to provide reactive elements and frequency selective devices suitable for use in or as filters, equalizers and other frequency-attenuation or frequency-impedance modifying networks.

In another aspect, the purpose of the invention is to alter the current and potential distribution that normally exists within a uniform wave guide and in such manner as to modify the transmission characteristics thereof.

Other purposes and objectives will appear in the following description of several specific embodiments of the invention. In the accompanying drawings,

Figs. 1 to 4A are diagrammatic representations of certain types of electromagnetic waves that may exist within a hollow metallic guide;

Fig. 5 indicates the current flow accompanying one type of wave and Fig. 5A represents the corresponding equivalent transmission network;

Fig. 6 shows the current flow accompanying another characteristic type of wave and Fig. 6A is the corresponding equivalent network;

Figs. 7 and 8 show structures in accordance with the invention in which the shunt arm of the equivalent network is of the modified form indicated in Fig. 7A;

Figs. 9 and 10 show structures in accordance with the invention in which the series arms of the equivalent networks are modified as indicated in Fig. 10A;

Figs. 11, 12 and 13 are embodiments of the invention utilizing iris diaphragms;

Figs. 14 and 14A utilize resonant chambers; and

Figs. 15 and 16 utilize metallic conductors.

Referring more particularly now to Figs. 1 to 4A there are shown longitudinal and transverse sections of a tubular metallic wave guide and the distribution of the electric and the magnetic fields of typical electromagnetic waves in such a guide. Although as disclosed in my copending application, supra, it is possible to set up an indefinite number of types of waves in tubular metallic guides, those shown herein are illustrative.

All of the various kinds of waves which may be propagated within a hollow metallic guide may be classified in two groups which may be designated, respectively, as transverse magnetic and transverse electric. Transverse magnetic waves, of which Figs. 1 and 2 are illustrative, are characterized by the fact that the magnetic field lies entirely in transverse sections of the guide with no longitudinal component, whereas the electric field has in general both a transverse and a longitudinal component. Transverse electric waves, of which Figs. 3 and 4 are illustrative, are characterized by the fact that the electric field lies entirely in transverse sections with no longitudinal component, whereas the magnetic field has in general both a transverse and a longitudinal component.

This invention will be described primarily with reference to a metallic pipe guide of circular cross-section, but it will be evident that the invention is applicable to guides of other cross-sectional shapes, such as rectangular.

The distribution of the displacement and conduction currents in a hollow metallic wave guide depends upon the particular type of wave transmitted but for the purposes of explaining the invention it will be sufficient to use a few examples only. Thus Fig. 5 relates to the type of wave shown in Fig. 1, which may be specially designated as the circular magnetic type inasmuch as the magnetic field consists of circular lines coaxial with the guide and lying transversely thereto. The electric field, it will be noted, is radial at some points along the guide and at other points longitudinal, the lines of electric intensity terminating on the metallic tube. There is a corresponding flow of displacement current in the dielectric medium, radially as represented by the arrows 10 in Fig. 5 and longitudinally as represented by the arrows 11. This current flow is continued within the tube wall in the form of conduction current, represented by the arrows 12, so that closed current loops are formed lying partly within the tube wall and partly in the enclosed dielectric medium. The current in the tube wall is longitudinal; the longitudinal current in the dielectric medium, most intense at the axis of the guide, is virtually a return current, analogous to the return current in the central conductor of a coaxial conductor transmission line.

Accompanying any flow of conduction current is a certain amount of inductive reactance and, similarly, there is always capacitive reactance associated with the flow of displacement current. Applying this principle to the current distribution appearing in Fig. 5 the equivalent circuit network represented in Fig. 5A may be derived. Thus the inductive reactance associated with the conduction current flow in the tube may be represented by the inductance 22 of Fig. 5A and the capacitive reactance associated with the longitudinal displacement current may be represented by the capacitance 21 which is connected in series relation with respect to the inductance inasmuch as each current may be considered as the return flow of the other. Similarly, the radial flow of displacement current is represented in Fig. 5A as a capacitance 20, which is connected across the circuit in view of the transverse disposition of the corresponding displacement current within the guide.

Although the reactances of the sytem are represented in Fig. 5A by discrete capacitances and inductances, it is to be understood, of course, that the reactances are distributed uniformly in the guide and that a large number of the network sections of Fig. 5A would be required to accurately reproduce the frequency characteristics of the system. The same may be said for all of the equivalent networks herein disclosed. If the flow of current in the transverse magnetic wave of the first order and first mode, represented in Figs. 2 and 2A, is analyzed, it will be found that the equivalent network is of the same form as that shown in Fig. 5A. In fact Fig. 5A is applicable to any transverse magnetic wave traveling in a hollow metallic guide.

As a further illustration of the principles upon which the present invention rests reference is to be had to Figs. 6 and 6A which relate specifically to transverse electric waves of the first order and first mode, represented in Fig. 4. In this case, the electric field in the dielectric medium is wholly transverse and it may be repesented at any one point instantaneously by the solid lines shown in Fig. 4A. At the same instant the electric field one-half wave-length removed from the transverse section represented at Fig. 4A is the same except that its direction is reversed. Within this half wave-length section there is a longitudinal conduction current flow in one direction through one-half of the tube and an oppositely-directed flow of current in the other half of the tube as represented by the arrows 15 and 16 in Fig. 6. A current loop is thus established, the ends of which lie in the dielectric medium and the sides of which lie in the tube wall. Referring to Fig. 6, still another current path may be identified, for the transverse displacement current, represented by the arrow 13 in Fig. 6, finds a conductive return path circumferentially around the guide as represented by the arrows 14.

Having established the current paths associated with the waves, the basis has been laid for the equivalent circuit network shown in Fig. 6A. Thus, the longitudinal current flow being wholly of the conduction current type, the only series element in the equivalent network is an inductance 25. Transversely of the guide there are two current paths, one wholly through the dielectric medium and the other wholly through the metallic tube. Hence the shunt arm of the equivalent network comprises a capacitance 23 corresponding to the dielectric path and a parallel-connected inductance 24 corresponding to the conduction current path.

The equivalent circuit network for the circular electric wave depicted in Figs. 3 and 3A, and for all other transverse electric waves, is of the form shown in Fig. 6A.

It may be noted with reference to Fig. 6 that the current density of both the longitudinal and the transverse conduction currents varies sinusoidally around the circumference of the guide and that the longitudinal current density is greatest at diametrically opposite points aligned with arrow 13 whereas the transverse conduction current density is greatest at points 90 degrees circumferentially removed therefrom.

From the foregoing analysis of hollow metallic guides the fact that they are inherently frequency discriminating is evident. Finite sections of such guides can accordingly be utilized as elements of various types of electrical networks such as filters, distortion correcting networks, etc. It is often desirable, however, to have a structure the equivalent network of which is somewhat different than those networks represented in Figs. 5A and 6A, and in accordance with my invention this objective is attained by modifications of the basic structure represented in Figs. 5 and 6.

Fig. 7 may be considered as a modification of the system illustrated in Fig. 6, the modification consisting in splitting the guide longitudinally and providing lateral flanges 27 and 28 on each portion of the guide, juxtaposed to provide a capacitive effect between them. In this case the currents represented by the arrows 14 in Fig. 6 now are required to pass as displacement currents through the dielectric medium separating the flanges. The medium being capacitively reactive in nature, this is equivalent to inserting a capacitance 29 in series with the shunt inductance 24 of Fig. 7A. The capacitance per unit length due to the flanges 27 and 28 will be determined in part by the spacing between the flanges and in part by the radial distance to which they extend. The capacitance may be increased by the introduction of dielectric separators between the flanges. A certain amount of inductance, too, is associated with the flanges for conduction currents flow through them, and this additional inductance is effectively series-connected in the shunt arm of the equivalent network.

In the transmission of waves through the structure represented in Fig. 7 there would be a tendency for radiation to occur outward through the space between the flanges 27 and 28, this giving rise to a certain amount of attenuation which may or may not be desired. Such radiation losses, if undesired, may be kept to a low value by spacing the flanges closely together or by metallically joining the outer edges as shown in Fig. 8. The reactance due to the flanges will then be somewhat different than in the case of Fig. 7 since in the latter the radially propagated waves look into the equivalent of an open-circuited transmission line, whereas in the former they look into the equivalent of a short-circuited transmission line. The impedance per unit length of guide due to the flanges, looking radially into the space between them, is given by the relationship

$$Z = -iZ_0 \cot \beta L \qquad (1)$$

where Z_0 is the characteristic impedance of a transmission line comprising two flat members one unit length in width and with the spacing actually present between flanges 27 and 28, β is

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

where λ is the wave-length, and L is the transverse dimension of the flanges. It is to be understood that in this type of transmission the wave-lengths are short, and in accordance with wellknown circuital theory it will be recognized that the reactance will be capacitive if the length L has a value between zero and a quarter wave-length and that it will be inductive if the length L lies between the values

$$\frac{\lambda}{4} \text{ and } \frac{\lambda}{2}$$

these reactances varying from one to the other cyclically as the radial length of the flanges increases.

In the case of Fig. 8 the corresponding equation for the impedance is

$$Z = iZ_0 \tan \beta L \qquad (2)$$

from which it becomes evident that the reactance is inductive if the radial length lies between the values zero and

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

and capacitive if the length lies between

$$\frac{\lambda}{4} \quad \frac{\lambda}{2}$$

From the foregoing it is evident that with the structures illustrated in Figs. 7 and 8 one can introduce in series with the inductance 24 of Fig. 7A the equivalent of a capacitance or an inductance and that the magnitude of the quantity can be controlled over a wide range. If distributed reactance is desired the splitting of the guide should extend over several wave-lengths but if on the other hand lumped reactance is desired the length should be small compared with the wave-length.

In Fig. 9 is shown a structure in accordance with the present invention which introduces capacitive reactance in the path of longitudinal conduction current flowing in the metallic portion of the guide. In this case the guide is cut transversely and annular metallic flanges 30 and 31 are provided at the juxtaposed ends of the guide, so disposed as to leave a small dielectric gap between them. The equivalent network depends upon the type of wave used, but in any type where there is longitudinal current flow in the metal tube the effect of the longitudinal discontinuity is to introduce a capacitive reactance in series with the corresponding arm of the equivalent network. Thus if the structure is operated with waves of the type indicated in Figs. 1 and 5 the equivalent network is as shown in Fig. 5A where 21 now represents a lumped capacitance of greater magnitude. Fig. 10A is similarly applicable for waves of the type indicated in Figs. 4 and 6 where a capacitive reactance is now present in the series arm of the network. Here again the magnitude of the capacitance is dependent in part on the spacing between the flanges 30 and 31 and part on their extension radially. The magnitude of the capacitance may be modified by the introduction of dielectric material between the flanges. Although these flanges may extend completely around the guide as represented in Fig. 9 they may extend only part way and be in the form of sectorial plates. Normally the spacing between the flanges would be short compared with the wave-length.

A shielding cap may be provided over the junction of the two portions of guide or the annular opening may be closed at its periphery as illustrated in Fig. 10, thus preventing the escape of energy through the space between the two flanges.

It has been stated that the effect of the break between the two flanges would be that of a series capacitance. This is true, of course, only if the radial dimension of the flanges is small compared with the wave-length. Otherwise, there would be an effect similar to that described in connection with Figs. 7 and 8. Thus for Fig. 9 Equation 1 would be applicable and for Fig. 10 Equation 2 would be applicable. Again it becomes apparent that by suitable choice of the dimensions of the flanges the series reactance could be made capacitive or inductive thus giving wide latitude and great flexibility in the design of an equivalent network of desired characteristics.

In Figs. 7 to 10 as many of the structures shown may be placed successively one after another as may be desired thus providing still greater latitude and flexibility in the design of equivalent networks.

Still other forms of impedance elements are appropriate for furthering the objects of the present invention. Thus in Fig. 11 there is shown a tubular metallic wave guide with an iris diaphragm 35 interposed therein. The diaphragm is essentially metallic and it has an opening therein preferably coaxial with the guide and of the same cross-sectional configuration, circular therefore in the case illustrated. Means may be provided for varying the size of the aperture. A diaphragm of this kind, inasmuch as it provides a metallic path for the flow of current transversely of the guide, possesses the characteristic of shunt inductance. The equivalent networks are similar therefore to those shown in Figs. 5A and 6A except for the addition of an inductance in series with the other element or elements in the shunt arm of the network. Which form the network is to take depends, of course, on the type of wave, that is, on whether it is transverse electric or transverse magnetic.

Fig. 12 shows an impedance element utilizing iris diaphragms; it may be compared with Fig. 9. In this case, the guide is cut transversely and irises 36 are placed at each free end, the two ends being then brought in close juxtaposition to yield a capacity effect between the iris members. The combination modifies the characteristics of the normal guide by the addition of shunt inductance adjustably controlled by the size of the iris opening and a series capacitance depending on the size and spacing of the iris diaphragms, the capacitance being effective in the manner described with reference to Fig. 9. The size of the iris openings is further a means for controlling the coupling between the two sections of guide.

Fig. 13 shows an extension of the arrangement of Figs. 11 and 12. In this figure, two irises 37 and 38 are spaced apart with any desired interval. Between them may be placed at appropriate positions other impedance elements Z_1, Z_2 and Z_3 which may take on any desired characteristic, such as that of attenuation members.

In Fig. 14 a different form of substantially lumped reactance is shown. In this case, an annular chamber 105 is provided into which power may be allowed to pass through an annular aperture 106. The aperture may be comparatively small and need not extend completely around the guide. Preferably the aperture should be adjustable as indicated by the arrows. In addition, an iris 107 is located within the chamber 105, thus giving to the chamber with its associated aperture a definite reactance by which it may be adapted for one purpose or another.

If it be desired that the reactance shall be concentrated at one point along the guide the arrangement of Fig. 14A may be used. In this case the opening to the surrounding chamber occupies a small length along the guide but the walls of the chamber flare out to give a relatively large volume. At the same time an annular adjustable aperture 108 may be provided. By proper choice of the volume, the dimensions and the positions of the various elements, an impedance element of wide flexibility can be obtained.

In Figs. 15 and 16 are shown other impedance elements adapted to modify the characteristics of a hollow metallic guide. In Fig. 16 there is shown bridged from one side to the other of the guide a conducting element 110 which may be given one form or another, such as that of a coil, to determine the magnitude of the equivalent shunt inductance. Still another form of such shunt inductance is shown at 111 where there is a bent wire the length of which is adjustable and which is given such curvature as to yield a definite inductive reactance. Such devices as that of 110 and 111 may be introduced at any intermediate point in the guide or they may be introduced at the end of the guide as shown in Fig. 16, in which case the bent wire serves to modify the terminating impedance of the guide making it possible to alter the extent to which reflection occurs at that point.

What is claimed is:

1. An impedance element in a high frequency transmission system comprising a metallic pipe split longitudinally and carrying within it high frequency electromagnetic waves that are accompanied by the flow of corresponding conduction currents peripherally around said pipe.

2. An impedance element in a high frequency transmission system comprising a metallic pipe split transversely and carrying within it high frequency electromagnetic waves of such nature that they are propagated only at frequencies above a critical frequency related to the transverse dimensions of said pipe.

3. In a high frequency transmission system, a wave guide comprising a metallic pipe for the transmission therein of electromagnetic waves at frequencies above the cut-off frequency of said guide, a section of said pipe having certain portions, normally traversed by conduction currents, replaced by a dielectric medium for the flow of corresponding displacement currents.

4. As a frequency-impedance modifying element, a section of wave guide having a metallic sheath and carrying within it high frequency electromagnetic waves accompanied by a longitudinal flow of conduction current in said sheath and by a longitudinal field component within the dielectric medium within said sheath, said sheath including a dielectric portion in which said current flows as displacement current, whereby the equivalent circuit of said section of guide includes a series capacitance.

5. As a frequency-impedance modifying element, a section of wave guide having a metallic sheath and carrying within it a band of high frequency electromagnetic waves accompanied by a flow of conduction current in a transverse path within said sheath, said sheath including a dielectric portion in which said current flows as displacement current, said dielectric portion being of such extent that the equivalent circuit of said section of guide includes a shunt capacitance that has a substantial reactance of a frequency within said band.

6. In a high frequency transmission system, two sections of wave guide each consisting essentially of a metallic pipe, juxtaposed in axial alignment with a small peripheral gap separating them, and means for propagating through said sections of guide high frequency electromagnetic waves of the transverse magnetic type, said gap being of such width that the effective series capacitance thereof has a significant effect on the transmission characteristics of said system within the operating frequency range.

7. In a high frequency transmission system, a section of wave guide consisting essentially of two semi-cylindrical metal portions disposed with longitudinal gaps between the edges thereof, and means for propagating through said section of guide high frequency electromagnetic waves of a type accompanied by a transverse flow of current through said metal portions and across said gaps, said section of guide constituting a lumped impedance element having an effective shunt capacitance.

8. A combination in accordance with claim 6 comprising metallic plate-like members for increasing the capacitance of said peripheral gap.

9. A combination in accordance with claim 7 comprising metallic flanges on said semi-cylindrical portions so disposed as to increase the flow of displacement current across said longitudinal gaps.

10. A combination in accordance with claim 6 comprising in addition interior annular metallic flanges at each of the juxtaposed ends of said sections of guide.

11. A wave guide comprising a body of dielectric of limited cross-section, means for propagating through said guide high frequency electromagnetic waves characterized in that at least one of the fields, electric and magnetic, has an intensity component in the direction of wave propagation, and means for introducing a lumped impedance in said guide comprising a guide section in certain peripheral regions of which the current flow is of either the conduction or the displacement kind but opposite in kind to the current flowing in the corresponding regions of a normal guide section.

12. In a dielectrically guided wave system, a guide comprising a dielectric bounded by a surface of dielectric discontinuity and possessing a characteristic impedance, means for introducing a series lumped reactance comprising a transverse interruption in the guide, and flanges in capacitive relation on the adjacent ends of the two guide portions, the flanges being of such radial dimensions as to give series capacitive or inductive reactance as desired for the frequency of the wave to be propagated.

13. In an electric wave guide system, a hollow metal guide, means for transmitting through said guide electromagnetic waves the frequency of which exceeds the cut-off frequency of said guide, and means for introducing shunt capacity consisting of longitudinal slots in said metal guide.

14. In a wave guide system, a hollow metal guide, said guide having a high-pass transmission cut-off at a frequency below that of the waves to be transmitted, and means for introducing shunt capacity consisting of longitudinal slots with longitudinal conducting wing members.

15. In a dielectrically guided wave system, a wave guide with the characteristics of continuously distributed inductance and capacity, means for introducing a lumped series capacity consisting of a transverse break in the guide with flanges on the two adjacent ends of the break to form a capacity between the flanges, the flanges being metallically closed at their outer edges.

16. In a signaling system, a wave guide comprising a metallic pipe for the transmission therethrough of electromagnetic waves at a frequency exceeding the transmission cut-off of said guide, said waves being accompanied by the flow of corresponding conduction currents in said pipe, an intermediate section of said pipe having a dielectric slit lying across the path of said conduction currents, metallic flanges defining a transmission line extending from said slit transversely of the axis of said guide, said line being metallically short-circuited at such distance from said slit that a substantial reactance is presented to the said waves in the guide.

17. A combination in accordance with claim 16 in which said flanges define a radial transmission line.

18. A combination in accordance with claim 16 in which said slit and flanges extend longitudinally of said section of pipe.

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