Feb. 26, 1946. F. B. LLEWELLYN 2,395,560

WAVE GUIDE

Filed Oct. 19, 1940

FIG. 1

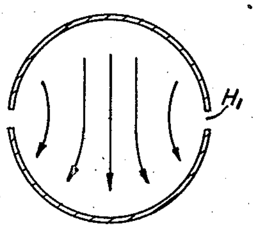


FIG. 2

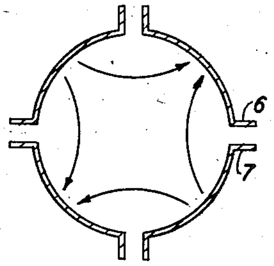


FIG. 3

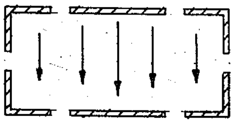


FIG. 4

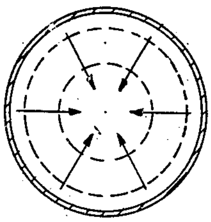


FIG. 5

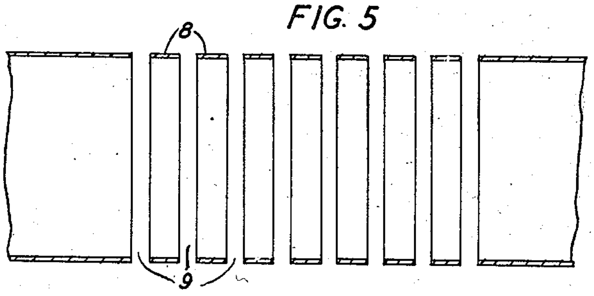


FIG. 6

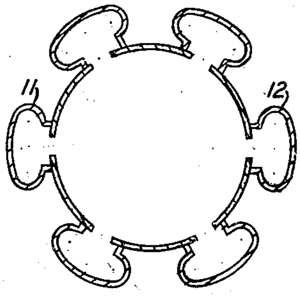


FIG. 7

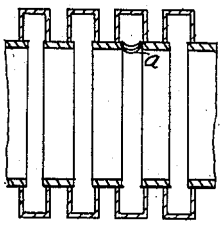
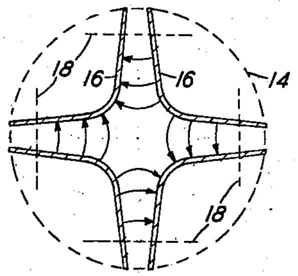


FIG. 8



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2,395,560

WAVE GUIDE

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Application October 19, 1940, Serial No. 361,876

12 Claims. (Cl. 178—44)

This invention relates to wave guides such as are used for dielectrically guided waves of high frequency and more specifically it relates to guides or sections of guides in which the velocity is changed substantially from that normally characteristic of a wave guide of corresponding transverse dimensions.

More specifically, the invention resides in so modifying the structure of a wave guide as to introduce the equivalent of reactances serving as loading to change the velocity of propagation of the wave in the resultant structure.

In one form of my invention I obtain these results by longitudinal slits in the wave guide, this being suitable for certain types of dielectric waves. In another form of my invention I divide the guide transversely into sections, this being suitable for certain other types of dielectrically guided waves.

The invention will be better understood by reference to the following specification and the accompanying drawing, in which:

Figs. 1 and 2 are cross-sections of circular wave guides supporting certain types of waves, each of these guides having longitudinal slits;

Fig. 3 is the cross-section of a similar wave guide but of rectangular cross-section;

Figs. 4 and 5 relate to wave guides transversely divided;

Figs. 6 and 7 are modifications, respectively, of Figs. 1 and 5;

Fig. 8 is still a further modified form of wave guide.

The wave guides which I contemplate using are primarily hollow metal pipes. The distribution of potentials and currents in such a pipe will depend in part on the type of wave which is being propagated. Fig. 1 shows a cross-section of a circular wave guide in which there is indicated a type of wave identified as an H_{11} wave. For this type of wave the electric vector in the dielectric is confined to a transverse plane with no component in the direction of propagation, the general form of the electric field being as shown in the figure. The magnetic vector is in part transverse but has also a substantial longitudinal component. The displacement currents across the pipe give rise in general to conduction currents in the metal pipe, the currents being transverse to the length of the pipe. It has been found that by making longitudinal slits of the kind shown in Fig. 1 there is introduced in the path of the conduction currents series capacitance and that this serves as the equivalent of loading of such character as to increase the velocity of propagation of the wave in the pipe.

A similar arrangement is shown in Fig. 2 where again a pipe of circular cross-section is present for the transmission of H or magnetic waves of a higher mode as represented by the electric vectors in Fig. 2. For this case four longitudinal slits are provided. If one were to go to still higher modes, a correspondingly larger number of the longitudinal slits should be provided. Although for the type of wave shown in Fig. 1 only two slits are shown, there may be a larger number, equivalent to introducing a larger number of series capacitances in the path of the conduction currents traveling transversely in the metal pipe. In fact, this showing should be understood as only illustrating the principle involved inasmuch as for any substantial velocity modifying effect and for other reasons the number of slits should be such that the distance between them is small compared with the operating wave-length. While in Fig. 1 the wave guide pipe is shown as having simple slits, in Fig. 2 there is shown the additional feature of increasing the capacitance at each of the slits by radial extensions 6 and 7, these being present or not as desired and being extended to give as large a capacitance at each of the points as may be desired.

Fig. 3 shows the same principles of added reactance applied to a wave guide of rectangular cross-section, here again the conduction currents being peripheral and transverse to the length of pipe.

Fig. 4 is a cross-section of a circular wave guide in which there is being propagated a so-called E_{01} wave, this being a wave in which the magnetic field is entirely transverse with no longitudinal component and the electric vector has a radial component and also a longitudinal component. The conduction currents in such a case are longitudinal in the metal pipe. For this type of wave then I obtain the desired results by dividing the wave guide transversely into a number of sections such as shown in Fig. 5. Then the longitudinal currents encounter the equivalent of series capacitance, which serves as loading and increases the velocity of the wave. It is desirable that this loading should approximate to continuous loading and this is attained by making the portions 8 of the pipe and the spacings 9 between the portions both small compared to the wave-length.

It is well known that dielectric wave guides possess the characteristic of a definite cut-off frequency below which the wave cannot be propagated. For a given frequency the cross-section of the wave guide must be equal to or greater than a certain critical value if the wave is to be sustained in the guide. Inasmuch as the velocity has been increased in the wave guide of my structures described above, it is necessary that for a wave of a given frequency a wave guide of larger cross-sectional dimensions be used. With the large increase in velocity which I obtain, this permissible increase of the dimensions of the wave guide for a given desired cut-off frequency becomes in many instances highly significant. For example, it permits enlargement of the transverse dimensions of a guide to accommodate generating or other apparatus of a given size without at the same time so reducing the cut-off frequency that spurious wave types may appear. So also, increased velocity of propagation may be desirable to reduce phase shift in the transmission of high frequency waves from one point to another.

In each of the structures described above there is obtained an increase in the velocity of propagation. In some cases, however, I find it important to reduce the velocity. With reference to Fig. 1 such velocity reduction may be obtained by surrounding the slits with an enclosing conducting structure such as to change the capacitive loading to inductive loading. Such surrounding structures are shown at **11** and **12** in Fig. 6. Similarly, as shown in Fig. 7, enclosing structures over the slits **9** of Fig. 5 are provided to accomplish a similar result. These enclosing structures serve also to reduce radiation laterally from the guide.

My invention, as described above, has in mind particularly the provision of an element for use in dielectric wave guide technique, where one may at times desire a section of wave guide in which the velocity is low as compared with that of a guide not possessing the slits described above. Such an element is particularly desirable where one may wish to bring about certain phase adjustments or delay in one portion of a guide as compared with that in another. Still another application of my invention would be that in which the low velocity wave is to cooperate with a stream of electrons for one purpose or another. Such application is disclosed in detail in my copending application, Serial No. 335,660, filed May 17, 1940. In addition to some of the structures I have described herein, that copending application discloses still other dielectric wave guide structures of low velocity and the invention as herein described is intended to comprise such additional low velocity structures as are described therein.

Analysis of the field distribution in a structure such as that of Fig. 5 or Fig. 7 shows a tendency for concentration of the field across the gaps **9**, as shown at *a* in Fig. 7, with a corresponding decrease in the field along the axis. In some applications of these low velocity guide sections, it is desirable that the electric force shall be particularly intense near the axis especially if this field is to operate on electrons near that axis.

One method of concentrating the field near the axis is shown in Fig. 8. The outer dotted line represents a hypothetical guide **14** of circular cross-section with one mode of waves which may be transmitted therethrough. Certain equipotential surfaces are represented at **16**. If a conducting sheet conforming to the equipotential surface is introduced into the guide, it will not disturb the distribution of the field within the enclosed portion. One may then construct a dielectric guide made up of four surfaces such as **16** with the surface **14** eliminated. The outer portions of the structure may be cut off at any desired point such as indicated by dotted lines at **18** and closed by longitudinal inductive chambers as in Fig. 6. There will result then a guide section with longitudinal slits functioning as described in connection with Fig. 6, the structure in itself having a reduced velocity. In addition or alternatively, this wave guide structure may be divided transversely as indicated in Fig. 7 with further reduction in velocity and with less decrease in the intensity of the field along the axis than would otherwise be the case.

What is claimed is:

1. Metallic means defining a pipe-like electromagnetic wave guiding passage of low velocity of propagation, said metallic means being so divided into a multiplicity of parts that at each junction between said parts series loading reactance is introduced in the path of conduction current associated with the transmitted waves, the spacing between the successive junctions being small compared to the free space wave-length of the waves being propagated.

2. The combination of claim 1, characterized in this that the series loading reactance is inductive.

3. A dielectric wave guide section of low wave transmission velocity comprising a plurality of short portions of wave guide arranged in tandem with intervening spaces between the successive portions, the length of the intervening spaces being small compared to the free-space wave-length of the transmitted wave, and the said portions being so short that there are many of said spaces per wave-length.

4. The combination of claim 3, characterized by this that the short portions are hollow metallic pipes.

5. The combination of claim 3, characterized by this that the short portions are hollow metallic pipes and that the intervening spaces are enclosed by conducting chambers to reduce radiation losses.

6. In combination, metallic means defining an electromagnetic wave guiding passage adapted to inhibit wave radiation laterally therefrom, means for exciting the interior of said passage with electromagnetic waves, said metallic means comprising a multiplicity of systematically spaced parts, the wave impedance appearing at the spaces between said parts being reactive and the distance between said inter-part spaces being small compared with the length of said waves, whereby there are a plurality of said spaces per wave-length.

7. In combination, metallic means defining a pipe-like electromagnetic wave guiding passage adapted to inhibit wave radiation laterally therefrom, means for exciting the interior of said passage with electromagnetic waves, said pipe-like passage having a multiplicity of longitudinal slits therein spaced apart circumferentially of said passage and the spacing between the successive slits being small compared with the length of said waves, whereby said wave guiding passage has continuous reactive loading.

8. In combination, metallic means defining an electromagnetic wave guiding passage adapted to inhibit wave radiation laterally therefrom, means for exciting the interior of said passage with electromagnetic waves, said metallically de-

fined passage having a multiplicity of transverse breaks therein spaced apart along said passage, the spacing between said breaks being small compared with the length of said waves whereby said passage effectively has substantially continuous reactive loading.

9. In combination, metallic means defining an electromagnetic wave guiding passage adapted to inhibit wave radiation laterally therefrom, means for exciting the interior of said passage with electromagnetic waves, said metallic means comprising a multiplicity of systematically spaced parts, the wave impedance appearing at the spaces between said parts being capacitive and the distance between said spaces being small compared with the length of said waves, whereby the velocity of propagation is increased relative to the velocity in a wave guiding passage having the same transverse dimensions and a continuous boundary.

10. In combination, metallic means defining an electromagnetic wave guiding passage adapted to inhibit wave radiation laterally therefrom, means for exciting the interior of said passage with electromagnetic waves, said metallic means comprising a multiplicity of systematically spaced parts, the wave impedance appearing at the spaces between said parts being inductive and the distance between said spaces being small compared with the length of said waves, whereby the velocity of propagation is reduced relative to the velocity in a wave guiding passage having the same transverse dimensions and a continuous boundary.

11. In combination, metallic means defining a wave guiding passage for the transmission of ultra-high frequency electromagnetic waves, a succession of metallically bounded chambers along said passage, each surrounding said passage and having a circumferential connection thereto, there being many of said chambers per wave-length along said guide and said chambers being so proportioned as to present a substantial inductive reactance at said circumferential connection whereby said wave guiding passage has an effectively continuous inductive loading.

12. A combination in accordance with claim 11 in which more particularly said inductive reactance is of such order of magnitude that the phase velocity of wave transmission through said passage is substantially less than the velocity characteristic of light in the medium within said passage.

FREDERICK B. LLEWELLYN.