

July 16, 1957

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2,799,831

MICROWAVE CIRCUITS

Original Filed Aug. 30, 1955

2 Sheets-Sheet 1

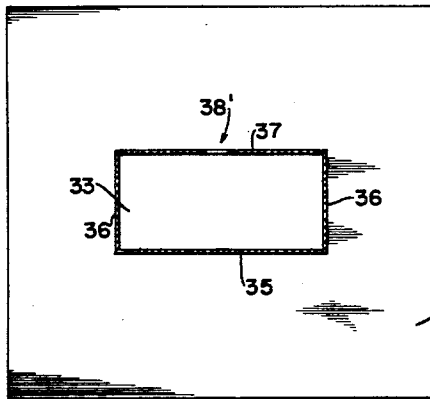


FIG. 8

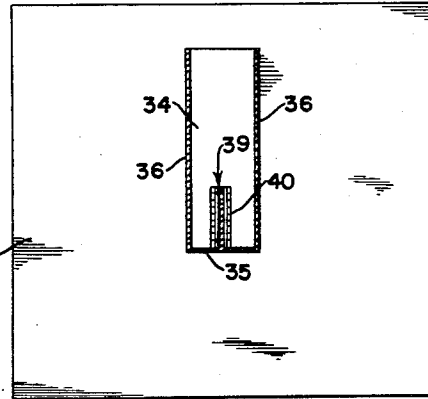


FIG. 9

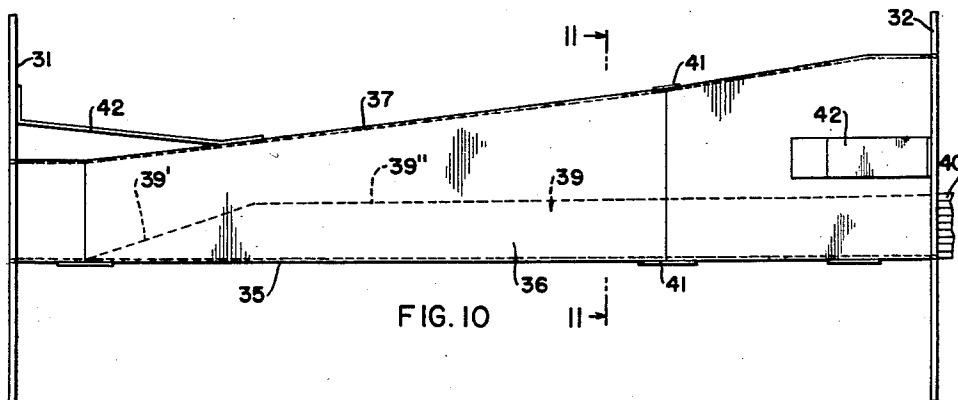


FIG. 10

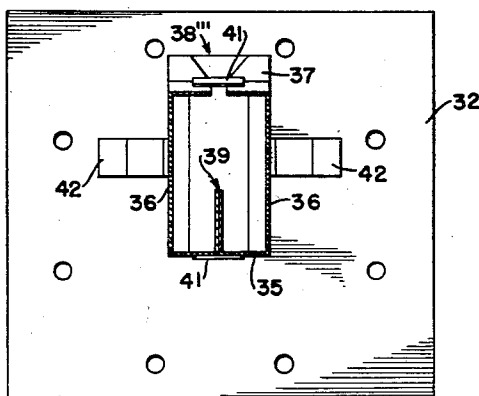


FIG. 11

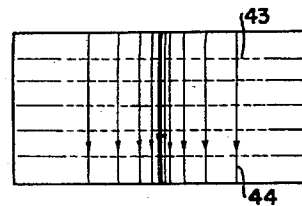


FIG. 12

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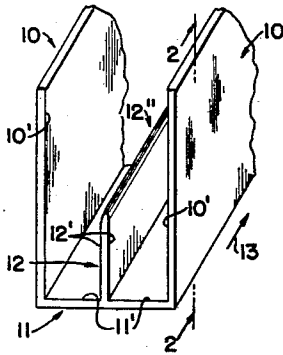


FIG. 1

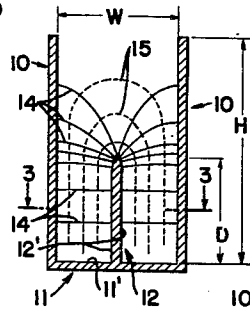


FIG. 2

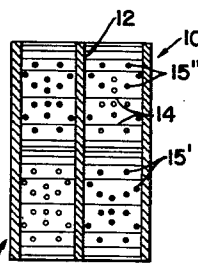
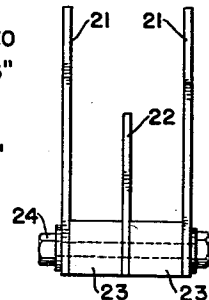


FIG. 3



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2,799,831

MICROWAVE CIRCUITS

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Original application August 30, 1955, Serial No. 531,323. Divided and this application August 24, 1956, Serial No. 610,433

3 Claims. (Cl. 333—34)

This invention relates to microwave transmission lines for guiding and conveying electromagnetic energy.

In the microwave region it is common to employ waveguide for transmitting electromagnetic energy. Although perhaps the widest use is above 3000 megacycles per second, waveguide is occasionally employed down to 1000 megacycles, and even at lower frequencies for high power applications.

The conventional waveguide consists of a metallic tube through which the electromagnetic energy is propagated. Although various cross-sectional configurations are possible, the most widely used waveguide has a rectangular cross-section.

It is often desirable to make measurements on waveguide in order to determine the losses therein, or the standing wave ratio, or to facilitate tuning associated apparatus, etc. This can be accomplished by slotting one wall of the waveguide and inserting a probe. Such slots are narrow compared with the width of the corresponding wall of the waveguide, thus limiting the size of probes that can be inserted therein. As the waveguide becomes smaller for higher frequencies, the problem becomes more severe. Also it is sometimes desirable to insert elements for loading, impedance matching, etc., and similar space difficulties arise.

In accordance with the present invention a transmission line, functioning generally on waveguide principles, is provided in which one wall may be left completely open so as to facilitate inserting probes for measuring or other purposes.

An additional advantage of the transmission line of the present invention is that the bandwidth for the dominant mode of operation may be made considerably greater than that of conventional rectangular waveguide, and yet the structure is mechanically simple and easy to fabricate.

The transmission line of the present invention is termed a "trough transmission line" because of its overall trough-like shape. Generally speaking, the line has sidewalls and a central member (which may be of fin-like shape) positioned therebetween with the conductive sides of the central member conductively connected to the sidewalls at the bottoms thereof, but the top wall may be left completely open. The top may be capped to keep the line free of dust and moisture, but the cap may be removed, e. g., for purposes of measurement, without substantially affecting the characteristics of the line. For certain relative dimensions, as described hereinafter, it is preferable to employ insulating caps of low dielectric constant, but with other relative dimensions it is possible to use a cap of conductive material without appreciably affecting the transmission line characteristics.

The transmission line may be used in place of other forms of waveguide or in place of coaxial transmission lines, or it may be used in conjunction therewith. When used with conventional rectangular waveguide provision must be made for coupling energy from the conventional waveguide to the trough transmission line of the present

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invention without excessive mismatch. In accordance with a further feature of the invention, a suitable transition section is provided. Usually the transition section will be used to couple extended sections of rectangular waveguide and trough waveguide, but in particular applications it can be used by itself.

The invention will be more fully understood by reference to the following description of specific embodiments thereof, taken in conjunction with the drawings, in which:

Fig. 1 shows in perspective a portion of a trough transmission line in accordance with the invention;

Fig. 2 is a cross-section of the transmission line of Fig. 1, showing the electric and magnetic fields for the dominant mode of operation;

Fig. 3 is a longitudinal section taken along the line 3—3 of Fig. 2;

Fig. 4 is an elevation from one end of a trough transmission line showing a suitable mechanical structure using stock materials;

Fig. 5 is an end view of a modification of the embodiment of Fig. 1;

Fig. 6 is a plan view of a rectangular waveguide-to-trough transformation;

Fig. 7 is a side elevation of Fig. 6;

Figs. 8 and 9 are cross-sections taken along the lines 8—8 and 9—9 of Fig. 6, respectively;

Fig. 10 illustrates certain constructional features employed in a practical embodiment;

Fig. 11 is a cross-section of the embodiment of Fig. 10 taken along the line 11—11 thereof; and

Fig. 12 is a diagram illustrating electric and magnetic fields of a rectangular waveguide in its dominant mode of operation.

Referring now to Fig. 1, an embodiment of the trough transmission line of the present invention is shown in one of its simplest forms. As shown, the sidewalls 10 extend transversely from a bottom wall 11, and a central member 12 is positioned between the sidewalls and likewise extends transversely from the bottom wall 11. As specifically illustrated, the central member 12 is fin-like in appearance, and for convenience will sometimes be termed a fin hereinafter. However, it may be made substantially wider than shown, if desired.

The several walls and bottom extend longitudinally of the line, as indicated by the arrow 13, and electromagnetic energy propagates down the line in the direction indicated by the arrow.

Preferably the sidewalls 10 and central member 12 are flat and parallel, as shown, with the central member positioned midway between the sidewalls. Also, preferably the bottom 11 is flat, as shown. However, considerable departure from the configuration illustrated is possible. For example, the sidewalls might be bowed and also the bottom given some curvature. It is possible also to depart somewhat from the flat configuration of the central member 12. In general, however, it is desirable to make the structure symmetrical about a plane passing through the central member 12, so that one side of the line is substantially a mirror image of the other, in order to avoid spurious modes.

The entire structure shown in Fig. 1 may be made of a suitable metal of high conductivity. However, since high frequency current flow is confined essentially to the inner surfaces of the sidewalls, designated 10', the upper surfaces 11' of the bottom, and the sides 12' of the central member, if desired only these surfaces need be of conductive material. If the entire unit is made of relatively inexpensive metal, the designated surfaces can be silver-plated or otherwise given a highly conductive surface coating so as to minimize losses.

Further modifications are possible which may be de-

sirable for particular applications. As will be explained hereinafter, substantially no component of current exists perpendicular to the free edge 12'' of the central member. Consequently it is possible to employ a sheet of insulating material covered on both sides with a conductive coating or foil, etc., as the central member 12. Further, although not preferred, it is possible to use two spaced sheets of conductive material as the central member 12, with a narrow opening therebetween to allow insertion of a narrow probe or other coupling means. In such case the two sheets will be joined to respective bottom surfaces, and the overall arrangement can be obtained by placing two U-shaped troughs beside each other, with the inner vertical surfaces shorter than the outer.

Fig. 2 shows the approximate configuration of electric and magnetic fields for the dominant mode of operation, it being understood that the dominant mode is that mode of operation which has the lowest cutoff frequency, and is the mode commonly employed in practice. In Fig. 2 the full lines 14 represent the field lines or lines of flux of the electric vector, and the dash lines 15 represent the field lines or lines of flux of the magnetic vector. It will be noted that the field lines of the electric vector extend from the conductive sides 12' of the central member to the inner surfaces of the respective sidewalls 10. The spacing between adjacent field lines 14 is an indication of the relative intensity of the electric field. At the bottom of the trough, near surfaces 11'', the intensity of the electric field is small. The field becomes progressively more intense in the upwards direction along the central member and is a maximum at the free edge of the central member. On the other hand, transverse currents on the sides of the central member 12 vary from a minimum at the free edge to a maximum at its base. The field lines of the electric vector are generally parallel to the bottom surfaces in the regions where the central member 12 lies directly opposite the sidewalls. In the regions above the free edge of the central member, the field lines extend upwards along curved paths to the respective sidewalls. It will be recognized that the field lines of the electric vector are everywhere substantially transverse to the direction of propagation down the line.

In Fig. 3 the field lines of the electric vector are again shown by full lines 14 extending between the central member 12 and the sidewalls 10, and the intensity of the field is indicated by the spacing of the lines. Since Fig. 3 is a longitudinal section, the field lines of the magnetic vector are seen end-on, solid dots 15' representing the magnetic vector directed toward the observer and open dots 15'' indicating the magnetic vector directed away from the observer. The configuration of the fields in Fig. 3 is to be visualized as moving longitudinally (that is, upwards in the plane of the paper) at a speed equal to the phase velocity of the electromagnetic wave.

Referring back to Fig. 2, the cutoff wavelength (λ_c) is primarily determined by the electrical height of the central member 12, and in general the cutoff wavelength is approximately that at which the electrical height of member 12 is a quarter-wavelength. Thus, the electrical height of member 12 should in general not exceed a quarter-wavelength of the lowest frequency to be transmitted. As will be understood by those in the art, the electrical height of member 12 will ordinarily be somewhat greater than the physical height due to fringing of the electrical field and spreading of the magnetic field around its upper edge.

Explaining this somewhat more fully, the electric field shown by lines 14 has approximately a half-sine wave distribution which is substantially zero at the bottom surface 11' of one side of central member, increases to a maximum near the free edge of member 12, and decreases to substantially zero at the bottom surface on the other side. A path exists in the space about member 12 whose length is approximately one-half that of the longest

wave that is capable of being transmitted by the waveguide.

The effective length of this path is subject to calculation for a given configuration by methods known in the art. It has been found that for most practical purposes the effective length L is closely approximated by the following equation:

$$L=2D+0.44W \quad (1)$$

where D is the height of the central member and W is the separation of the sidewalls as illustrated in Fig. 2. This equation is given as a general guide which has been found valuable in practice and is believed to be reasonably accurate. However, it is not insisted upon.

Considering the functioning of the central member 12 more generally, it possesses the property of transverse resonance at frequencies for which its height makes the effective path length L an odd integral multiple of a quarter of the cutoff wavelength. Due to the considerable fringing of the electric field, or so-called "end" effect, at the free edge of member 12, the cutoff wavelength is increased appreciably beyond that indicated by the physical height of the member.

It will be noted from Figs. 1 and 2 that the tops of the transmission line is completely open. Thus radiation might be expected to occur, with consequent loss of energy. This is prevented in the transmission line of the present invention by proper selection of the spacing W of the sidewalls and the amount by which the height of the sidewalls exceeds that of the central member 12.

In general, the spacing W should be less than a half-wavelength at the operating frequency of the line. If the line is intended to be operated over a range of frequencies, spacing W should not exceed a half-wavelength of the highest frequency in the desired range. The sidewalls 10 can then be extended upwardly sufficiently to reduce the radiation, or the coupling between the region within the waveguide and the region outside of it, to any desired value. In general, it is found that making the height of the sidewalls exceed that of the central member 12 by the spacing of the sidewalls, that is, by making $H-D$ equal to W , sufficient reduction of transverse radiation is obtained for most practical purposes, and it is preferred to extend the sidewalls by at least this amount. If W approaches a half-wavelength, then it is desirable to make $H-D$ considerably greater than W in order to secure sufficient reduction of transverse radiation. Furthermore, even with close spacing of the sidewalls, $H-D$ can be made considerably greater than W to further reduce radiation and consequent losses, or to reduce coupling with regions outside the waveguide.

The spacing of the sidewalls, W , also has an effect on the characteristic impedance of the line, and in general the characteristic impedance increases as the spacing W decreases.

Assuming that it is desirable to be able to operate at frequencies down to the region of cutoff, for this condition the following relationships apply:

$$W < \lambda_c / 2 \quad (2)$$

$$L = 2D - 0.44W = \lambda_c / 2 \quad (3)$$

By combining these equations the following relationship is obtained:

$$D > 0.14\lambda_c \quad (4)$$

This shows that the height of the central member 12 should be greater than approximately $0.14\lambda_c$ under the assumed conditions. If the spacing W is considerably less than a half-wavelength at the cutoff frequency, D can be correspondingly greater, but not to exceed $\lambda_c / 4$.

The foregoing discussion of relationships of the several dimensions is given as an aid to the ready practice of the invention, and is not intended to limit the invention thereto.

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With proper selection of dimensions, the trough waveguide of the present invention can be operated in its dominant mode over a range approximately three times the cutoff frequency before higher propagating modes of operation are supported. By way of contrast, conventional rectangular waveguide can be operated only over a range of approximately twice the cutoff frequency before higher propagating modes are supported. This is a considerable advantage of the present transmission line where broad band operation is sought, with freedom from higher propagating modes. In this event, the spacing W of the sidewalls is advantageously made less than a half-wavelength at the highest frequency in the range, and the sidewalls extended sufficiently to reduce radiation and consequent losses to a desired low value.

As will be apparent from Figs. 1 and 2, the top of the transmission line may be completely open to facilitate the insertion of probes for measuring or other purposes. However, in a practical application it may be undesired to leave the top open at all times. In such case a removable cap can be placed over the top. In general the material used for the cap and its position should be chosen so as not to affect materially the field distribution in the trough. If material of low dielectric constant approaching that of air is employed, the spacing and height of the sidewalls may be substantially the same as that employed for physically open-top line. For material of higher dielectric constant, and for conductive materials, it is desirable to increase the height of the sidewalls for a given spacing so that the field is negligibly small in the region of the cap.

In general, if the height of the sidewalls exceeds that of the central member 12 by about twice the spacing W , and if the spacing is substantially smaller than a half-wavelength at the operating frequency, the electric field at the top is approximately 54 db lower than the field at the edge of the fin. Capping with a conductive member or with a member of high dielectric constant will therefore not appreciably affect the electrical characteristics. For any other height of sidewalls the rule that, for spacings substantially smaller than a half-wavelength, the field decreases at the rate of approximately 27 db per spacing W (by which the sidewalls exceed the height of the central member) will permit the designer to compute the effect of the cap and choose suitable dimensions accordingly.

If desired, of course, the cap may be made integral with the sidewalls, rather than removable.

The structure illustrated in Fig. 1 can be fabricated in any desired manner. To avoid tooling where only small quantities are involved, it is desirable to make the line of stock materials readily available. Sheet metal can be bent into the required shape and secured by soldering, brazing, spot welding, etc. Fig. 4 shows an alternative in which sidewalls 21 and the central member or fin 22 are flat strips of sheet metal and the bottom is made of two lengths 23 of somewhat thicker metal, with the assemblage held together by suitable means such as bolts 24. In this type of construction care should be taken to insure good electrical contact between the several members. Any desired length of line can be made in this manner by using suitable lengths of material.

Referring now to Fig. 5, a modification of the structure of Fig. 1 is shown in which the width of the bottom surfaces is markedly reduced. Central member 12 is positioned between sidewalls 45 and the conductive sides of member 12 are conductively connected to the sidewalls 45 by narrow conductive surfaces 25' of the bottom 25. Sidewalls 45 are arranged to slant inwards toward the bottoms thereof rather than being parallel as in Fig. 1. The spacing W' of the tops of the sidewalls 45 is advantageously less than a half-wavelength at the highest operating frequency and the height H' of the sidewalls preferably exceeds the height of the central member 12 by at least the spacing W' to prevent transverse radiation.

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The sidewalls may be still higher to further reduce transverse radiation, as explained hereinbefore.

In some instances the angle between sidewalls 45 may be chosen so that the sidewalls can be flat and still provide a sufficiently narrow spacing W' for a desired height H' . For wider angles, the upper portions 45' may be at an angle to the remainder of the sidewalls, as specifically shown, to restrict the spacing W' .

If desired, the width of the bottom surfaces 25 may be further reduced to substantially zero, in which case the conductive sides of the central member 12 join the sidewalls 45 at the bottoms thereof respectively. Also, instead of forming the sidewalls of flat sections, they may be curved. In such case, it is preferable to keep the lateral spacing of all corresponding points of the sidewalls less than a half-wavelength. As in the case of Fig. 1, it is desirable to keep the structure of Fig. 5, and modifications thereof, symmetrical about a plane through the central member 12 so as to avoid spurious modes.

The exact distribution of the electric and magnetic fields for the configuration of Fig. 5 will differ somewhat from that shown in Figs. 2 and 3, but the general character of the distribution will be similar.

Figs. 6-11 are various views of a transformation which may be used to couple a length of conventional rectangular waveguide to a length of trough waveguide with small loss and impedance mismatch. Alternately, the transformation can be used by itself if desired for a particular application. The transformation can be considered as composed of an end section A whose cross-section is that of the rectangular waveguide to which it is to be connected, an intermediate section B, and another end section C whose configuration is selected to match that of the trough waveguide with which it is to be connected.

End plates 31 and 32 are provided to facilitate connection to adjacent line sections. End plate 31 has a rectangular opening 33 therein (Fig. 8) whose cross-section matches that of the waveguide with which it is to be associated. The opposite plate 32 has a rectangular opening 34 therein (Fig. 9) to match the trough waveguide with which it is to be associated. It will be noted that the rectangular opening 33 at the waveguide end has its longer dimension horizontal, whereas the opening 34 at the trough end has its longer dimension vertical.

A conductive bottom 35, sidewalls 36 and a slotted top 37 are provided. In section A the four walls constitute substantially a continuation of the waveguide with which it is to be attached, and the slot 38 in this region (designated 38') makes it analogous to a slotted waveguide. At the opposite end the top of section C is open to match the trough waveguide. Section C contains a central member or fin 39 to match that of the trough waveguide with which it is to be attached. Preferably member 39 is conductively attached to an associated trough waveguide, and to this end a spring clip arrangement 40 may be provided.

The fin 39 extends into the intermediate section B beneath the portion 38'' of slot 38, and tapers to substantially zero height at the end thereof toward section A, as indicated at 39'. On the other hand, the height of the sidewalls of section B gradually increases in the direction of section C. Near the section C the slot 38 widens at 38''' to match the open trough configuration of section C. The angle of taper of section 39' preferably does not exceed 45°, and may be made considerably less, as shown. Also the intermediate section 39'' may be given a slight taper, with advantage.

Fig. 12 shows the fields of a conventional rectangular waveguide operating in its dominant mode. The electric field is shown by full lines 44 and the magnetic field by dash lines 43. By comparison with the field configuration in the trough waveguide shown in Fig. 2, it will be observed that the electric fields in the two sections are

at approximately right angles to each other near the bottom.

The provision of slot 38, the tapering of fin 39, the gradual increase in the height of the sidewalls, and the widening of the slot at 38" all combine to provide a gradual transition in the electric and magnetic fields between the two end sections.

When the transformation is used with a trough waveguide whose cross-section is like that of Fig. 5, the bottom of the intermediate section B may be tapered to a narrower width at section C, and may approach a point if the sidewalls of section C intersect the central member thereof. Also the sidewalls of section B may be gradually inclined or curved so as to match the selected configuration of the trough at section C.

Various modifications of the transformation illustrated may be made in practice to meet the conditions of a particular application. As has been pointed out, with sufficiently high sidewalls of the trough section, it is possible to use a conductive top without interfering with the operation thereof. Hence in some cases it may be possible to omit the widening of the slot at 38" and gradually reduce the width of the slot to zero. Also the point at which the central member tapers to zero may be changed, and the point at which the slot 38 begins (toward section A) may be altered.

Although a suitable arrangement for coupling a conventional waveguide to a trough waveguide has been described, it is possible to introduce and remove energy from the trough by means of probes and coupling elements known in the art for coupling to conventional waveguide, cavities, etc. Such feed systems should preferably be designed to have a major electric or magnetic field component (or both), which is in the direction of the corresponding component in the trough waveguide, as discussed in connection with Figs. 2 and 3, for the dominant mode of operation. Also, it is desirable to employ feed systems which are structurally symmetrical with respect to the plane of the fin or central member 12, so as to avoid the possibility of setting up waves which will propagate between the sidewalls in a direction perpendicular to the longitudinal axis of the trough.

A novel coaxial-to-trough line coupling is described in a copending application of Eugene G. Fubini and Henry S. Keen, entitled "Microwave Circuits," filed concurrently herewith.

Referring now to Figs. 9 and 10 a transition unit made of sheet metal sections with suitable joining sections 41 and supporting brackets 42 is shown. Soldering and brazing may be employed as desired to insure electrical continuity and mechanical strength.

The invention has been described in connection with specific embodiments thereof. It will be understood that many variations and alternations are possible within the scope of the invention, and may be made as suits the designer or meets the needs of a particular application.

In the specification and claims use has been made of terms such as "bottom," "top," "sidewalls," "height," etc., in order to define the relationships in convenient language which can be readily understood. The employment of such terms, however, is not intended to mean that the transmission line must be used in practice with the "top" up, the "bottom" down, etc., as specifically illustrated, since the trough may be inverted, or laid on its side, etc., as meets the requirements of a particular application.

This application is a division of application Serial No. 531,323, filed August 30, 1955, for "Microwave Circuits."

I claim:

1. A microwave waveguide transformation which comprises a first waveguide section of substantially rectangular

cross-section in which the top and bottom are wider than the sidewalls thereof, a second trough waveguide section having a pair of spaced conductive side walls and a central member having conductive sides positioned between the sidewalls, the conductive sides of said central member being conductively connected to the sidewalls at the bottoms thereof respectively, an intermediate section having conductive bottom and sidewalls connecting bottom and sidewalls of said first and second sections respectively, and a conductive top in said intermediate section connecting at one end with the top of said first section and having a slot therein for a portion of the length thereof, said central member of the second section extending into said intermediate section with at least a portion of the length thereof beneath said slot and tapering to substantially zero height toward said first section.

2. A microwave waveguide transformation which comprises a first waveguide section of substantially rectangular cross-section in which the top and bottom are wider than the sidewalls thereof, a second trough waveguide section having a pair of spaced sidewalls, a central member having conductive sides positioned between the sidewalls and a bottom connecting the sidewalls with the conductive sides of the central member, the sidewalls and central member of said second section extending transversely from the bottom thereof and the height of the sidewalls being substantially greater than the height of the central member, the top of said second section being substantially open between the tops of the sidewalls thereof, an intermediate section having conductive bottom and sidewalls connecting bottom and sidewalls of said first and second sections respectively, and a conductive top in said intermediate section connecting at one end with the top of said first section and having a slot therein which is narrow near said first section and widens to substantially the full width of the top at said second section, said central member of the second section extending into said intermediate section and tapering to substantially zero height toward said first section.

3. A microwave waveguide transformation which comprises a first waveguide section of substantially rectangular cross-section in which the top and bottom are wider than the sidewalls thereof, a second trough waveguide section having substantially flat conductive bottom, sidewalls and central member, the sidewalls and central member of said second section extending substantially perpendicularly from the bottom thereof with the central member midway between the sidewalls, the top of said second section being substantially open for substantially the full width of the bottom thereof and the height of the sidewalls exceeding the height of the central member by at least the spacing of the sidewalls, the bottom of the first section being substantially wider than the bottom of the second section and the sidewalls of the second section being substantially greater in height than the sidewalls of the first section, an intermediate section having conductive tapering bottom and sidewalls joining bottom and sidewalls of said first and second sections respectively, and a conductive top in said intermediate section connecting at one end with the top of said first section and having a longitudinal slot midway of the width thereof which is narrow near said first section and widens to substantially the full width of the top at said second section, said central member of the second section extending into said intermediate section midway between the walls thereof and connected with the bottom thereof and tapering to substantially zero height toward said first section.

No references cited.