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2,836,798

MICROWAVE TRANSMISSION LINES

Filed Feb. 13, 1953

2 Sheets-Sheet 1

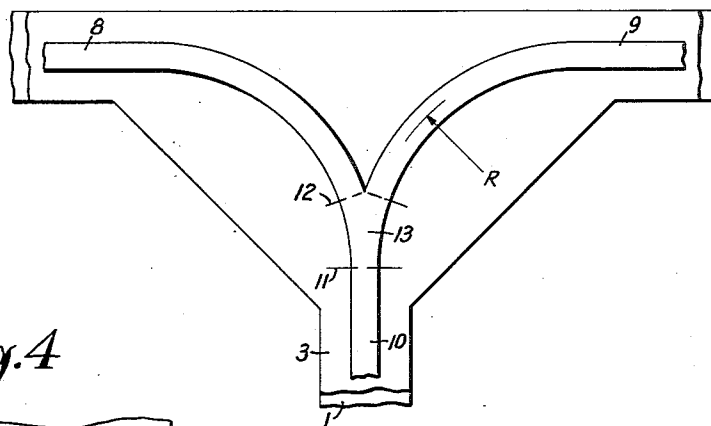
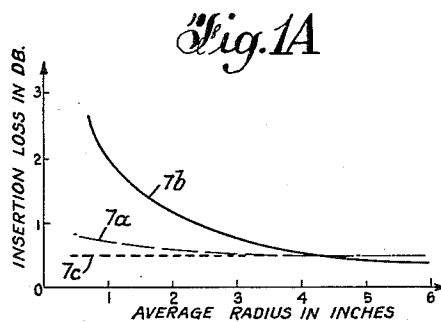
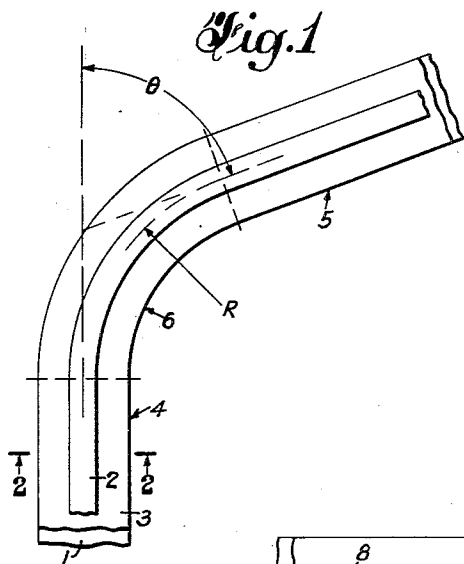


Fig. 4

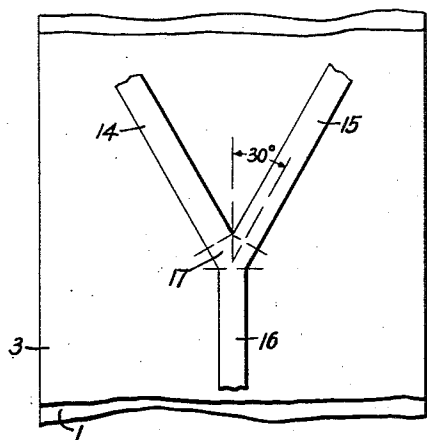
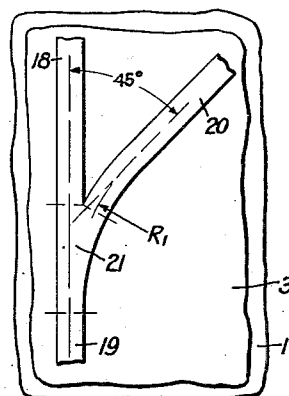


Fig. 5



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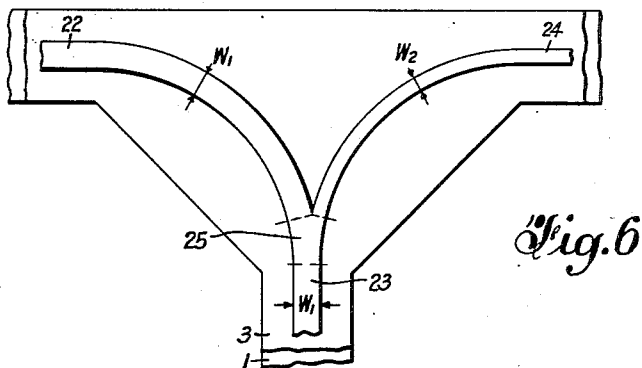


Fig. 6

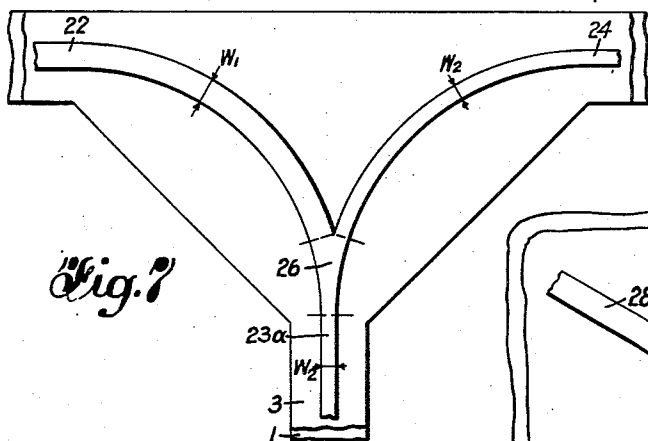


Fig. 7

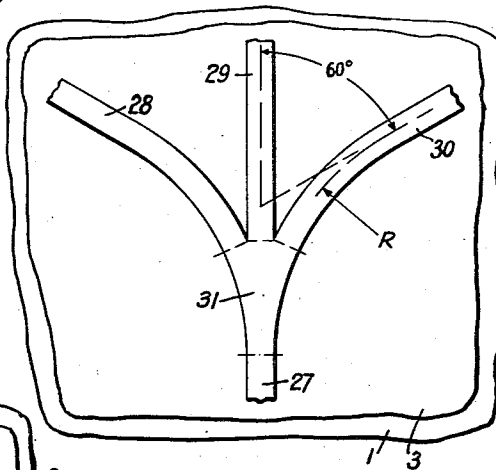


Fig. 8

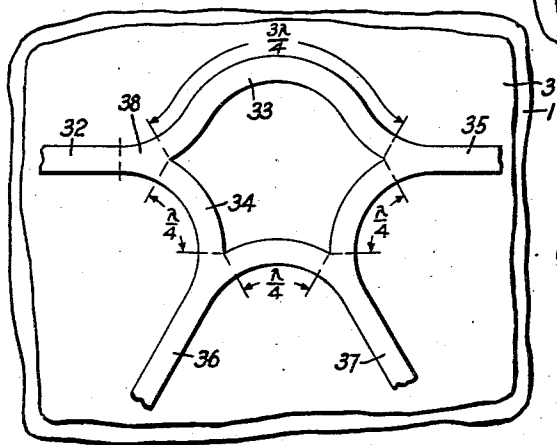


Fig. 9

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MICROWAVE TRANSMISSION LINES

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Application February 13, 1953, Serial No. 336,671

3 Claims. (Cl. 333—9)

This invention relates to ultra high frequency and microwave transmission lines and more particularly to networks of such lines including bends, power dividing and hybrid junctions.

In the copending applications of D. D. Grieg and H. F. Engelmann, Serial No. 234,502, filed June 30, 1951, now Patent No. 2,721,312 and M. Arditi and P. Parzen, Serial No. 286,764, filed May 8, 1952, now Patent No. 2,774,046 microwave transmission lines comprising generally a "line-above-ground" type of wave guide, over which ultra high frequency and microwave energy may be propagated in a mode simulating a TEM mode, are shown. In this type of wave guide, a planar conductor is employed as a "ground" conductor with a line conductor disposed in spaced parallel relation thereto by means of a strip or layer of dielectric material. The line and planar conductors are preferably of different widths, that is, the planar conductor is made wider than the line conductor so that it appears as an infinite conducting surface to the line conductor, thereby insuring an electric field distribution characterized generally by the TEM mode. For example, the field distribution is believed to be similar to that which occurs between one of the conductors of a truly parallel conductor system and the neutral plane between such conductors. The important parameters of this type of wave guide are the width of the line conductor and the dielectric spacing between the line conductor and the planar conductor.

One of the objects of this invention is to provide a transmission line or wave guide of the character described above with angular bends, power dividers or hybrid junctions with substantially no loss by radiation.

Another object of the invention is to provide such lines with angular bends between 30 and 90° at a minimum radius with substantially no loss by radiation.

Still another object is to provide a network of such lines as a power divider, the network including angular bends at the power dividing junction thereof.

A further object is to provide a network of such lines as a hybrid coupler, the network including angular bends and power dividers.

When a transmission line or wave guide of the line-above-ground type is provided with a bend up to about 30°, the bend may be abrupt without appreciable loss due to radiation. When the line has an angular bend greater than 30° the bend must be curved to avoid or minimize loss due to radiation. The reason for this is that the electric and magnetic fields of microwave energy propagated along the line tend to establish higher order modes at such bends unless the bend is sufficiently curved to effect gradual deviation of the fields. I have discovered that this curvature becomes critical as the radius of curvature is reduced below a given value particularly where the deviation exceeds 30°.

One of the features of this invention is the selection of a minimum radius permissible for bends exceeding about 30° for minimum loss due to radiation, this selec-

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tion being dependent largely on the size of the angle and the width of the line conductor where flat strip conductors and a given conductor spacing are employed.

Another feature is the manner of dividing wave energy propagated along such lines whereby impedance transformation is obtained in the shaping of the junction, whether of the energy dividing type or the hybrid type. Where the angle of a branch line with respect to the main line exceeds about 30°, the branch lines are curved into the junction with a radius insuring minimum loss due to radiation.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a plan view of a microwave transmission line of the "line-above-ground" type incorporating an angular bend in accordance with the principles of this invention;

Fig. 1A is a graph of curves showing insertion loss due to radiation and the fixed conductor and dielectric losses for different radius of curvature for a 90° angle for two different widths of line conductor;

Fig. 2 is a cross-sectional view taken along line 2—2 of Fig. 1;

Fig. 3 is a plan view of an energy divider wherein the branch lines angle off from the main line at an angle of 90°;

Fig. 4 is a view in plan of an energy divider wherein the branch lines angle off at about 30° from the main line;

Fig. 5 is a plan view of an energy divider wherein one branch thereof angles off from the main line while the other branch continues linearly with respect to the main line;

Figs. 6 and 7 are plan views of energy dividers wherein the division of energy is controlled by the width of the branch lines;

Fig. 8 is a plan view of an energy divider wherein the energy is divided between three branches; and

Fig. 9 is a plan view of a hybrid junction corresponding generally to the magic "T."

Referring to Figs. 1 and 2, the transmission line or wave guide comprises a first or planar conductor 1, a second or line conductor 2 spaced apart by a thin strip or layer of dielectric material 3. The two conductors 1 and 2 are preferably of flat strip form, the planar conductor being wider than the line conductor so that propagation of microwave energy therealong is similar to the TEM mode as hereinbefore explained. The dielectric material may be of polystyrene, polyethylene, "Teflon," fiberglass or laminated fiberglass impregnated with "Teflon," quartz, or other suitable material of high dielectric quality. The conductors 1 and 2 may be formed on the dielectric strip by any of the known printed circuit techniques, one suitable method being an etching process.

The transmission line shown in Fig. 1 comprises a first section 4 and a second section 5 disposed at an angle to each other to form a right angle or L-shaped bend. Interconnecting these two sections is a third section 6, the planar conductors of all three sections being connected together as an integral continuous planar strip conductor. The line conductors 2 of the three sections are connected together as an integral continuous strip conductor curved at a radius R.

In making plain angular bends of the line conductor 2 of this type of transmission line it has been found that loss due to radiation is negligible for small angular bends, i. e. deviation from a straight line, up to approximately 30°. As the angle θ becomes greater than 30° the loss

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due to radiation increases and becomes an important factor. The reason for this loss is believed to be the establishment of higher order modes due to the discontinuity provided by the angular bend in the transmission line.

Referring more particularly to Fig. 1a two curves are shown indicating the insertion loss due to radiation at the bend and fixed conductor and dielectric losses for different radius of curvature of 90° bends, one curve 7a being for a line conductor of 1/8" width and the other curve 7b being for a line conductor of 1/2" width. The level 7c indicates approximately the fixed conductor and dielectric losses of the test specimen. The bend for which the test data was taken to obtain these curves was in accordance with the construction shown in Figs. 1 and 2. The dielectric employed was polystyrene 1/4" thick. The frequency was 9000 megacycles per second and the line conductor 2 was copper foil 0.0015" thick.

It is readily seen from the curve 7a for the 1/8" line conductor that for values of radius greater than 3" the loss is substantially constant and that as the radius is reduced below 3" the loss increases. From the curve 7b for the 1/2" line the loss starts to increase when the radius is decreased below 4". These two points at 3" and 4" on the curves represent the minimum radius of curvature permissible for minimum loss due to radiation.

The following formula gives the minimum radius of curvature for minimum loss due to radiation for various widths line conductors up to a 90° angle. This expression was obtained from examining the results of a limited number of tests and is therefore regarded as a close approximation only. The basis for determining the minimum radius was that radius of curvature in excess of which a bend exhibited no improvement in measured insertion loss. The formula is as follows:

$$R = (0.73W + 0.28) \theta^{2/3} 10^{-3}$$

wherein R is the average radius of curvature in inches, W is the width of the line conductor in inches and θ is the angle in degrees of the bend deviating from a straight line. This formula while taken from data obtained at frequency of 9000 megacycles per second, should be varied as the frequency is changed, it being observed that as the frequency increases the value of the minimum radius for minimum loss due to radiation increases. It should also be understood that this formula has reference to a dielectric spacing such as indicated above and that for other dielectrics and other spacings, other variables must be added to the formula. For example, decreased spacing of the conductors would result in a decrease in the minimum radius permissible for minimum loss due to radiation.

In Fig. 3 a symmetrical power divider is shown wherein two branch line conductors 8 and 9 diverge from a main line 10 forming 90° angles with respect thereto. The minimum permissible curvature of the bends joining the branches with the main line is determined in accordance with the foregoing disclosure in connection with bends. It will be noted that between the lines 11 and 12 there is a gradual increase in the width of the main line conductor 10 until it is twice its width at line 12 where it divides into branches 8 and 9. This section 13 between lines 11 and 12 is in effect a transformer which provides an impedance match between the two branch lines and the main line. By employing this gradual transition between the main and branch lines no other special impedance matching arrangements are required and the branch lines are of the same characteristic impedance as the main line. It was also found desirable to extend the curvature of the outer edges of the branch conductors throughout the transformer section so that the edges of the main conductor are tangent to this curvature. Further, by following this form, unity input VSWR (voltage standing wave ratio) can be closely approximated. In a model where each branch deviated at 60° from the main input line with R=2 inches the VSWR was 1.09.

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In Fig. 4 a similar symmetrical power divider is shown wherein branch lines 14 and 15 deviate about 30° with respect to the longitudinal axis of the main line 16. In this form, since the angle of deviation is no greater than 30°, the problem of bend curvature does not arise. The junction of the branch lines may, therefore, be made directly into the main line. It will be observed, however, that in this form a transformer section 17 is incorporated in the junction, thereby providing a proper impedance match between the main line and the two branch lines.

In Fig. 5 an asymmetrical power divider is shown wherein one branch 18 is a continuation of the main branch 19 while the other branch 20 is deviated at an angle of approximately 45°. Since this deviation is greater than 30° it is advisable to introduce curvature in the junction as indicated by R₁ which for this model was selected equal to 3 inches. It will be observed, however, that in this type of junction there is again an impedance matching section 21. However, since the branch 20 is a linear extension of the main branch 19 it is favored in this form in the power division ratio. According to tests for insertion losses into the branches, the insertion loss for an angular deviation for branch 20 of 45° was 3.6 db for branch 18 and 4.8 db for branch 20. For an angular deviation of branch 20 of 90° with the same radius of curvature (R₁=3 inches) the insertion loss for branch 18 was 3.5 db and for branch 20 4.6 db. The input VSWR for the 45° model was 1.11 and for the 90° model was 1.15.

In Figs. 6 and 7, two forms of power dividers are shown wherein the power is unequally divided between two branches. In Fig. 6 branch 22 is maintained the same width W₁ as the main line 23. The branch 23 is of a different width W₂, here shown to be one-half the width of W₁, and is joined to the main line thereby forming therewith an impedance transformer section 25. The power division is directly proportional to the width of the two branches at the output of the transformer section, the power being divided approximately two-thirds to branch 22 and one-third to branch 24. In Fig. 7 the width of the two branches 22 and 24 are the same as in Fig. 6, while the main line 23a is shown to have the width of branch 24. It will be observed that the transformer section 26 is necessarily longer than the transformer section 25 because of this relationship. The power division, however, is substantially the same, that is, approximately proportional to the width of the two branches 22 and 24 at the output of the transformer section 26.

In Fig. 8 I have shown a junction wherein the main line 27 is divided into three branches 28, 29 and 30, the branch 29 being a continuation of main line 27 while branches 28 and 30 deviate angularly with respect thereto. The branch lines in this junction are shown to have the same width as the main line. The transformer section 31 varies between the width of the main line 27 and three times that width at the output side thereof. The power division in this form is substantially equal with respect to the two branches 28 and 30 while the branch 29 is favored because of its linear connection to the main branch. Test data taken for angles of deviation for branches 28 and 30 of 60° from the longitudinal axis of the main branch 27 shows an insertion loss in db's of 6, 5.3 and 6 for the branches 28, 29 and 30, respectively. In another test where the branches 28 and 30 deviated from the longitudinal axis of branch 27 by 30° the division was substantially identical to the one for the 60° deviation of the branches 28 and 30. In these tests the radius of curvature R was approximately 3 inches for each angle and the input VSWR measured 1.07 for the 60° model and 1.02 for the 30° model.

In Fig. 9 a hybrid junction is shown where the line conductor 32 branches into two loop conductors 33 and 34 which join to form a branch line conductor 35. Each loop conductor is selected three-quarters of a wavelength

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or three-quarters plus an integral multiple of wavelengths. The loop conductor 34 has two other branches connected thereto as indicated at 36 and 37, the spacing of these branches being equal, and as shown are one-quarter wavelength measured along the center lines of the line conductors. As in the case of loop conductors 33 and 34, the spacing between branches 32—35, 36—37 and 37—35 may be increased by an integral multiple of the operating wavelength, or any two arcs may be increased by a half wavelength. Each line connected to the hybrid loop is connected through a transformation section 38 as previously described thereby providing for proper impedance matching for line conductors of equal width. For power entering the loop from branch 32, the power divides between branches 35 and 36 to the exclusion of 37. Likewise, power entering the loop from branch 35 divides between branches 32 and 37 to the exclusion of branch 36 because of the hybrid characteristic of the junction.

In all of the power dividers and hybrid junctions illustrated a planar conductor 1 underlies completely the line conductor and branch conductor configurations of the junctions to form in conjunction with each branch a high frequency wave propagating wave guide, the fields of which simulate a TEM mode. By maintaining the curvature of the bends of the branches at not less than a minimum radius according to the disclosure for bends a minimum loss is experienced due to radiation at the junctions. By making each junction with an incorporated impedance transformer section proper impedance matching is obtained.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made by way of example only and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A hybrid radio frequency network comprising a planar conductor, first, second, third and fourth line conductors, a loop conductor, means maintaining said line and loop conductors in dielectrically spaced substantially parallel relation to said planar conductor to form therewith a plurality of waveguides, each of said conductors being of flat strip configuration, the space between said planar conductor and said line conductors and said loop conductors being conductively open along the lateral edges of said conductors and therefore subject to radiation losses due to discontinuities such as sharp bends in said conductors, impedance transformers coupling the line waveguides to the looped waveguide at spaced points so selected that wave energy propagated along one of said line waveguides splits in said looped waveguide for flow out of two of the other line waveguides to the exclusion of the fourth line waveguide, each said impedance transformer having a conductor section with one end coupled to one of said line conductors and matching the characteristic impedance of the line waveguide thereof, and another end having portions coupled to adjacent conductor legs of said looped waveguide and matching respectively the characteristic impedances thereof, the width of said conductor section

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being varied gradually between the ends thereof, said looped conductor, when viewed from the inside of said loop, having at least three convex portions and a fourth portion, said fourth portion having two convex sections connected by a concave section, said spaced points defining the junctions of said portions.

2. A hybrid radio frequency network according to claim 1, wherein the adjacent conductor legs of said looped waveguide deviate angularly to opposite sides of the longitudinal axis of the line conductor coupled thereto, the conductor legs being curved, the radius of curvature thereof being limited for minimum loss due to radiation for deviation angles between 30 and 90°, the value of said radius being proportional to the width of the curved conductor.

3. In a radio frequency network at least four main waveguides and a plurality of branch waveguides connected to each of said main waveguides, each of said main and branch waveguides consisting of a first conductor, a second conductor and means maintaining said conductors in dielectrically spaced substantially parallel relation, each of said conductors being of flat strip configuration, said first conductor being wider than said second conductor so that said first conductor presents substantially a planar surface with respect to said second conductor, the space between said first and second conductors being conductively open along the lateral edges of said conductors and therefore subject to radiation losses due to discontinuities such as sharp bends in said conductors, and an impedance transformer coupling said main waveguide to said branch waveguide including a conductor section with one end thereof coupled to the second conductor of and matching the characteristic impedance of said main waveguide, and another end having portions coupled to the second conductors of and matching respectively the characteristic impedances of said branch waveguides, the width of said conductor section being varied gradually between the ends thereof, the second conductors of said branched waveguides forming a looped hybrid junction, the first conductors of all said waveguides being coupled together as a continuous planar conductor underlying all of said second conductors, said looped hybrid junction when viewed from the inside of said looped hybrid junction having at least three convex portions and a fourth portion, said fourth portion having two convex sections connected by a concave section.

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