

Sept. 15, 1959

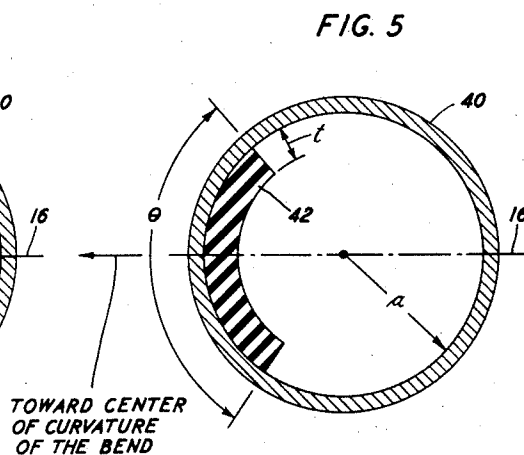
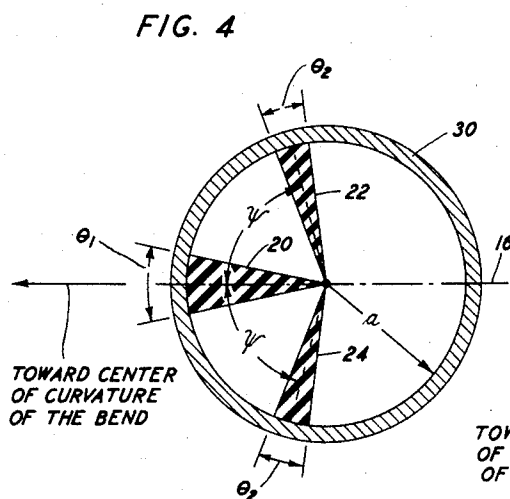
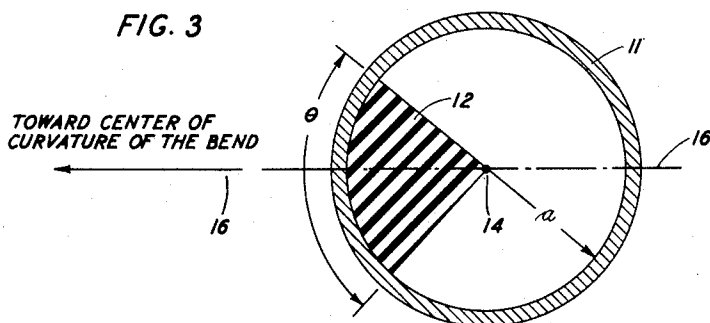
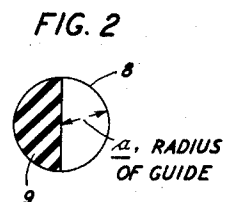
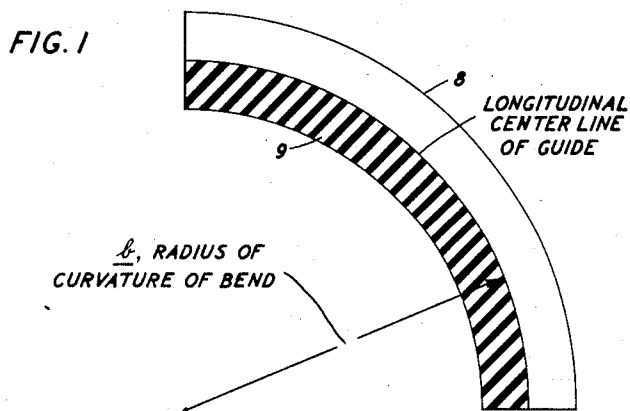
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2,904,759

MODE CONVERSION IN WAVE GUIDES

Filed April 26, 1956

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 6

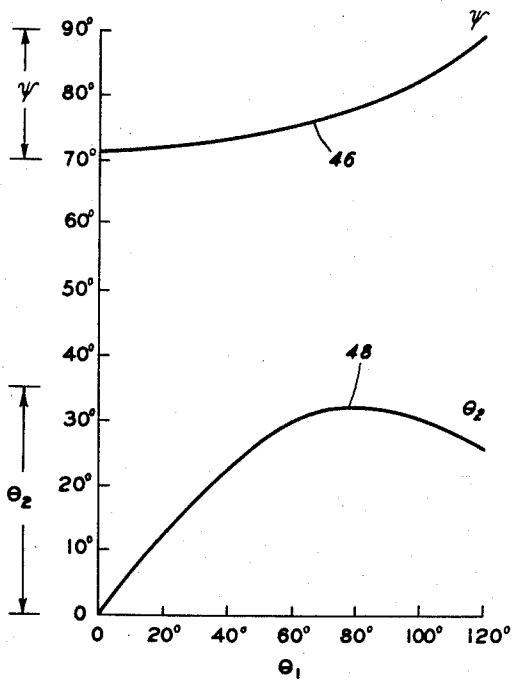


FIG. 7

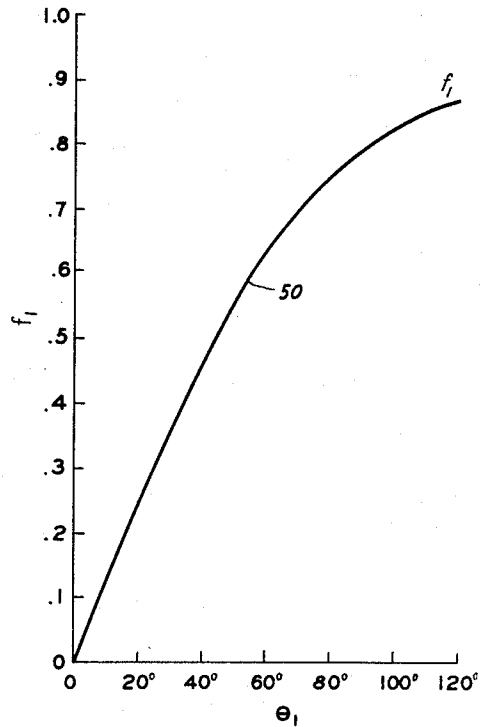


FIG. 8

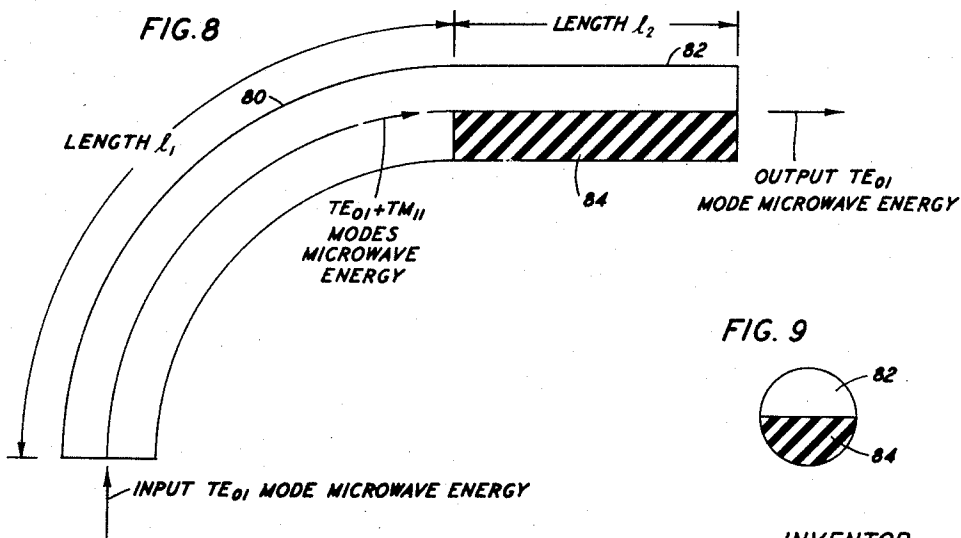


FIG. 9



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2,904,759

MODE CONVERSION IN WAVE GUIDES

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Application April 26, 1956, Serial No. 580,914

8 Claims. (Cl. 333—98)

This invention relates to novel specific arrangements for compensating for or suppressing spurious modes into which the TE_{01} mode of microwave energy tends to be converted when transmitted through curved portions of a round wave guide (single tubular conductor wave guide). More specifically it relates to novel, improved, specific arrangements of the general types to which my copending applications Serial No. 226,869, filed May 17, 1951, and Serial No. 255,836, filed November 10, 1951 are directed. These applications matured into Patents 2,762,982 and 2,762,981, respectively, both granted September 11, 1956. This application is a continuation-in-part of my above-mentioned copending application, Serial No. 226,869.

It has been recognized for several years that a major problem in the transmission of the TE_{01} mode, or lowest order circular electric wave, of microwave energy through multimode round wave guides is the question of negotiating bends without encountering serious conversion into unwanted or spurious modes. Theoretical studies (see M. Jouguet, Cables et Transmission, vol. 1, pages 133-153, 1947; W. J. Albersheim, Bell System Technical Journal, vol. 28, pages 1-32, for January 1949; etc.) have shown that a gentle bend couples the TE_{01} mode to the TE_{11} , TE_{12} , TE_{13} , etc., modes and to the TM_{11} mode. The tendency of the TE_{01} mode to convert into the TM_{11} mode presents the most serious problem, since the latter mode has the same phase velocity as the TE_{01} mode in a perfectly conducting straight guide. It follows that power introduced in the TE_{01} mode at the beginning of a gradual bend will be essentially completely transferred to the TM_{11} mode at odd multiples of a certain critical bending angle θ_c . The angle θ_c is proportional to the ratio of wavelength to guide radius but independent of bending radius; in other words, power transfer cannot be avoided merely by using a sufficiently gentle bend.

S. E. Miller, in the Proceedings of the I.R.E. vol. 40, pages 1104-1113, for September 1952, has discussed a number of methods for transmitting the circular electric wave (the TE_{01} mode) around bends with small net power loss to the TM_{11} mode. These methods are of two general types:

In the first type the TE_{01} mode, which is not itself a normal mode of the curved guide, is deliberately converted to a combination of TE_{01} and TM_{11} modes which represent a normal mode in the curved guide, or to a particular polarization of the TM_{11} mode which is another normal mode of the curved guide. After traversing the bend the energy is reconverted to the TE_{01} mode. A disadvantage of the normal mode approaches mentioned is that the mode conversions necessary at the ends of the bend are frequency sensitive, so that the frequency bandwidths over which they operate satisfactorily appear to be limited to the order of ten percent of the mid-frequency of the band.

A second approach to the bend problem is to break up, by some modification of the guide, the equality which exists between the propagation constants of the TE_{01} and TM_{11} modes in a perfectly conducting straight guide.

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The two modes are still coupled by the curvature of the guide, but as Miller has shown, the maximum power transfer will be small if there is sufficient difference between the phase constants or between the attenuation constants of the coupled modes. A difference in phase constants is provided, for example, by an elliptical guide or by one having a circularly corrugated wall. Differential attenuation may be introduced into the TM_{11} mode by a number of methods, for example, by making the guide out of spaced copper rings or a closely-wound wire helix surrounded by a lossy sheath. Unfortunately, the larger the guide diameter (in terms of wavelengths) the more difficult it is to get the separation of propagation constants necessary to negotiate a bend of given radius satisfactorily.

There is yet another solution to the bend problem which, in qualitative form, has been proposed in applicant's copending parent application, Serial No. 226,869, filed May 17, 1951, now United States Patent 2,762,982, issued September 11, 1956; particularly in Figs. 7 and 7A and the pertinent portions of the accompanying text; namely, to decouple the TE_{01} and TM_{11} modes in a curved guide by partially filling the cross-section of the curved guide with dielectric material. The dielectric must be arranged to produce a coupling between the TE_{01} and TM_{11} modes which is equal and opposite to the coupling produced by the curvature of the guide. This condition may be satisfied in a great variety of ways; but it is by no means the only requirement for a good bend compensator. In order to keep down the total insertion loss of the compensated bend to the TE_{01} mode, the power levels of all modes which are coupled to the TE_{01} mode must be kept low. Conversions to the higher circular electric modes (TE_{02} , TE_{03} , et cetera) are particularly undesirable, since those modes cannot be filtered out by selective attenuators and may give rise to troublesome resonances, on account of their low attenuations in the straight guide. Dielectric loss in the compensator is an important factor at millimeter wavelengths. Finally, the compensator must be simple to fabricate and the tolerances on dielectric permittivity and physical dimensions must not be overly critical.

A number of devices of the present invention are based upon the overall viewpoint that the modes in the compensated bend are equivalent to a set of coupled transmission lines, with couplings sufficiently small that the interaction of each mode with the TE_{01} mode may be considered separately. The size of coupling coefficient which can be tolerated depends upon the difference in phase velocities, if any, of the two modes. In general the less the phase velocity difference the lower the coupling which can be tolerated.

S. E. Miller in the Bell System Technical Journal for 1954, vol. 33 at pages 661-719, especially pages 677-692, presents a treatment of uniformly coupled transmission lines applicable to TE_{01} - TM_{11} mode coupling in plain and compensated bends. The coupling coefficients and related mathematical details have been worked out by applicant, using the generalized telegraphist's equations for wave guides as given by S. A. Schelkunoff, in the Bell System Technical Journal, vol. 31, No. 4, pages 784-801 for July 1952. Some results of the Jouguet theory for plain bends are confirmed by coupled-line theory. From a knowledge of the relative coupling coefficients resulting from curvature of the wave guide and the presence of the dielectric in the guide, the condition for decoupling the TE_{01} and TM_{11} modes in a compensated bend may be derived. Criteria may also be established for keeping the levels of all spurious modes low. The most serious offenders are those modes whose

phase velocities are closest to the phase velocity of the TE_{01} mode.

Three specific compensator designs based upon the above-noted analyses are described hereinunder, and evaluated with regard to their spurious mode conversions and their approximate dielectric losses.

In the first case, a dielectric sector of constant permittivity is attached to the inner surface of the bend (nearest the center of curvature) and the angle of the sector is determined to satisfy the decoupling condition. Such a sector promises to be an effective compensator if the guide is only large enough to propagate forty to fifty modes at the operating frequency, as, for example, a seven-eighth-inch diameter guide at a wavelength of 5.4 millimeters. In general, the number of modes which a wave guide will support is approximately equal to the quantity

$$\left(\frac{\pi a}{\lambda}\right)^2$$

where λ is the wavelength of the energy being transmitted and a is the radius of the wave guide.

Next we consider a compensator made of three dielectric sectors, whose angles and spacing are chosen to decouple, in addition to the TM_{11} and other modes, the modes TE_{21} and TE_{31} , which have phase velocities closest to the TE_{01} mode. The three sector compensator may be necessary if the guide is large enough to propagate 200 to 300 modes, for example, a two-inch diameter guide at 5.4 millimeters.

The last form considered is an annular sector of dielectric attached to the inner surface of the bent guide. The annular sector would be easy to fabricate, but since it tends to convert power into higher circular electric modes, its usefulness would appear to be limited to small guides in which all circular electric modes above TE_{01} are cut off.

Two numerical examples, namely the seven-eighth-inch diameter guide at 5.4 millimeters and the two-inch diameter guide at 5.4 millimeters, are carried through most of the illustrative discussion.

As a sample of the results, it appears possible to negotiate a 90 degree bend of radius twenty inches in the seven-eighth-inch diameter guide with an insertion loss of about 0.3 decibel. This assumes a single-sector polyfoam compensator of the present invention, having a relative permittivity of 1.036 and a loss tangent of 5×10^{-5} (polyfoam having approximately these constants is currently available). About 0.2 decibel of the quoted loss is due to mode conversions and the remainder to dielectric dissipation.

As a further example, it was found that for a two-inch guide with a three-sector polyfoam compensator conforming with the principles of the present invention, a bending radius of about twelve feet appears feasible. The total loss in a 90 degree bend is estimated as approximately 0.35 decibel, with approximately 0.1 decibel resulting from mode conversion and the remainder resulting from dielectric dissipation. The dielectric loss is proportional, of course, to the total bend angle, and, accordingly, for a 180 degree bend angle it would be double the above-mentioned figures.

A description is also included of a novel dielectric compensator which can be inserted in a straight section of the guide adjacent to a bend. This type merely takes the output mixture of TE_{01} and TM_{11} modes from a plain bend with a pure TE_{01} mode input, and reconverts it all to TE_{01} mode wave energy. It is essentially a broadband device and should not be confused with the "normal mode" arrangements which convert the TE_{01} mode at the input of the bend to a normal mode in the bend and reconvert the normal mode to TE_{01} mode at the output of the bend. The normal mode arrangements are essentially narrow band and are usually effective over only a frequency range of ten percent or so of the mid-fre-

quency of the transmitted band. While it appears unlikely that a smaller bending radius will be found feasible when the compensator is outside the bend than when it is inside, practical considerations, namely, ease of insertion and ease of adjustment, however, make this "terminal type" of compensator very attractive and it may, accordingly, find extensive use. The action of the terminal type compensator is reciprocal, i.e. it will convert a TE_{01} mode wave applied to the output end of the compensator to such a mixture of TE_{01} and TM_{11} modes that after traversing the bend the energy will emerge from the far end of the bend entirely as TE_{01} mode wave energy.

Accordingly a principal object of the invention is to facilitate the elimination of losses resulting from conversion of the TE_{01} mode of microwave energy into spurious modes in plane curved portions of a round, single conductor, wave guide transmission line.

Another object is to provide novel, conveniently employed, mode compensators or suppressors for use with curved portions of round single conductor wave guide.

Other and further objects, features and advantages of the present invention will become apparent during the course of the following detailed description of specific illustrative embodiments of the invention and from the appended claims.

In the accompanying drawings:

Figs. 1 and 2 show longitudinal and end views, respectively, of a mode suppressor or compensator of the invention divided out of applicant's above-mentioned co-pending parent application;

Fig. 3 illustrates a specific type of mode suppressor or compensator of the invention;

Fig. 4 illustrates a further specific type of mode suppressor or compensator of the invention;

Fig. 5 illustrates a still further specific type of mode suppressor or compensator of the invention;

Figs. 6 and 7 show curves relating various design parameters of the species of suppressor or compensator illustrated in Fig. 4; and

Figs. 8 and 9 show longitudinal and end views of a section of wave guide comprising a plane curved portion connected to a straight portion in which a specific form of mode converter of the invention is included.

In more detail in Fig. 1 and the end view Fig. 2, there is illustrated an embodiment of the present invention in which a dielectric mode transducer 9 is incorporated in a microwave device that tends to generate a spurious mode. The particular device shown is a 90 degree arcuate bend in a round wave guide 8 in which the energy is supplied in the TE_{01} mode. The theory of propagation of TE_{01} mode waves around a curved bend has been extensively treated in the literature, as noted hereinabove, and it has been shown that when such a bend is encountered, the applied TE_{01} mode waves are progressively converted into TM_{11} mode waves. These two modes have exactly the same phase velocity in a straight round wave guide and consequently when they are coupled by the curvature of the guide the conversion of TE_{01} mode waves to TM_{11} mode waves in a bend of wave guide may be partial or complete or there may even be several complete conversions from one mode to the other in alternation, depending upon the dimensions of the wave guide and the total angle of curvature of the bend.

In Figs. 1 and 2, the dielectric member 9 is disposed uniformly throughout the arcuate length of the bend of wave guide 8, in accordance with the principles of the present invention to generate from the operating mode (TE_{01}) the same mode that the bend itself tends to generate (TM_{11}). More particularly, the member 9 is proportioned to generate this mode with the same amplitude as that generated by the bend and with the same orientation. The relative phases, however, are in opposition so that the spurious mode (TM_{11}) generated by the

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bend is cancelled by that generated in member 9, as rapidly as it is formed. In general the centroid of the dielectric-filled area is displaced somewhat from the geometrical center of the guide cross-section in the direction of the center of curvature of the bend. The optimum position of the dielectric member 9 and the necessary cross-sectional area of member 9 can be readily calculated and several specific arrangements designed for specific operating conditions are described in detail hereunder by way of specific examples. In the arrangement of Figs. 1 and 2, the dielectric member has a cross-section which constitutes a 180 degree segment the chord of which is the diameter of the wave guide 8 which is perpendicular to the plane of the bend, i.e., the plane which includes the longitudinal axis of guide 8 and the radius of curvature of the bend. In a relatively sharp bend it may be necessary to use material having a dielectric constant substantially higher than the values heretofore suggested for such purposes, for complete cancellation of all of the TM₁₁ mode. In any such case the extremities of the dielectric member may be tapered to reduce the tendency toward impedance mismatch. More frequently, however, as will become apparent hereunder, a dielectric constant differing only slightly from that of free space will suffice and the impedance matching problem will be negligible.

Detailed designs of member 9 for specific arrangements can be arrived at empirically by altering the cross-sectional area or shape of the element until tests indicate that the emerging wave at the output end of the bend 8 is substantially free from TM₁₁ mode energy and other spurious mode energy. For guides capable of transmitting a large number of modes at the frequencies to be employed, however, purely empirical design is not very feasible. Other specific designs based upon mathematical analysis and taking into consideration other spurious modes into which the TE₀₁ mode energy input may be converted in passing through the bend are shown in the accompanying drawings and described in detail hereunder.

In Fig. 3, the circular cross-section 11 of a plane curved portion of a conductive round wave guide, such as guide 8 shown in Fig. 1 and having an internal radius designated a , is shown, point 14 representing the center of the circular cross-section through which the longitudinal axis of the portion of wave guide passes. The cross-section of a dielectric compensating or mode suppressing element 12, assembled in guide 11, is also shown in Fig. 3 and comprises a sectoral element, as shown, subtending an angle of θ degrees. This element extends longitudinally throughout the entire length of the plane curved portion of wave guide and is of uniform cross-section throughout the portion.

The bend, or plane curved portion, of the wave guide to be compensated has a radius of curvature b , as for guide 8 of Fig. 1, the center of curvature of the bend lying on an extension to the left of the center-line 16 of Fig. 3. Dielectric member 12 is symmetrically disposed about the plane of the bend, i.e., it is bisected by the plane which passes through the center of curvature of the bend and includes both the center line 16 and the longitudinal axis of the wave guide. Member 12 is also, obviously, on the side of the guide nearer to the center of curvature.

The arrangement illustrated by Fig. 3 represents one of the simplest ways to compensate a wave guide bend. The dielectric member 12 should have a relative permittivity of $(1+\delta)$ with respect to that of the dielectric filling the remainder of the guide, the latter dielectric normally being air or, in some instances, an inert dry gas, such as nitrogen, maintained at a pressure slightly above that of the surrounding atmosphere. As will become apparent during the following description, the factor δ is, for the majority of applications in accordance with the principles of the present invention, very small com-

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pared to unity. This is obviously desirable since no serious impedance mismatching will result if the permittivity of the dielectric is not appreciably greater than that of the remainder of the guide.

The total coupling coefficient κ between the TE₀₁ and TM₁₁ modes of microwave energy for the wave guide bend of Fig. 3 as described above with dielectric member 12 assembled therein is

$$\kappa = 0.18454\beta \frac{a}{b} - 0.12066\beta \sin \frac{\theta}{2} \quad (1)$$

where β is the phase constant

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

λ being the free space wavelength of the particular microwave frequency being employed. a is, of course, the radius of the guide and b is the radius of curvature of the bend.

In Equation 1 the first term on the right represents the coupling resulting from the curvature of the wave guide section and the second term represents that resulting from the presence of the dielectric compensating member 12. In order to completely decouple the above-mentioned two modes, therefore, κ should be zero.

Accordingly, equating the combination of the two right hand terms of Equation 1 to zero provides the "decoupling condition"

$$\theta = \frac{1.5295}{\sin \frac{\theta}{2}} \frac{a}{b} \quad (2)$$

It can be shown that if Relation 2 is satisfied, not only will the TE₀₁ mode be decoupled from the TM₁₁ mode, but also no circular magnetic modes (TM_{0m}) and no higher circular electric modes (TE₀₂, TE₀₃, etc.) are coupled to the TE₀₁ mode by the compensator 12 of Fig. 3. It can still further be shown that the coupling coefficients of the TE_{1m} and TM_{1m} modes do not depend upon the sector angle θ so long as the Relation 2 is satisfied.

It is found, however, that the modes TE₂₁ and TE₃₁, coupling to which is particularly undesirable because their phase velocities are relatively close to that of the TE₀₁ mode, can be decoupled only by an appropriate choice of the sector angle θ for each of these modes. A compromise value of the angle θ which equalizes the power transfer to each of the modes TE₂₁ and TE₃₁ is substantially 144 degrees.

By way of specific example, using a 144 degree sector of a dielectric for which δ is 0.036, in a wave guide having a diameter of $\frac{7}{8}$ inch and a bending radius of 19.5 inches, at a wavelength of 5.4 mm., the total mode conversion losses are found not to exceed 0.2 decibel or substantially or substantially 0.1 decibel to each of the modes TE₂₁ and TE₃₁.

For a wave guide having a diameter of 2 inches, however, if one attempts to keep the maximum mode conversion losses to the TE₂₁ and TE₃₁ modes simultaneously at not greater than 0.1 decibel with a single sector dielectric compensator it is found that no dielectric having a small enough value of δ to satisfy the decoupling Condition 2 is currently available. It is, therefore, necessary to employ a larger bending radius and a smaller sector angle. Under these circumstances the TE₃₁ mode is the worst spurious mode. More specifically, in the case of the 2-inch diameter guide, if δ is 0.033, a sector angle of only 4.7 degrees and a minimum bending radius of 94.3 feet are required to reduce the mode conversion loss to the TE₃₁ mode to .1 decibel. For this arrangement the mode conversion loss to the TE₂₁ mode is substantially less than 0.1 decibel, but the minimum bending radius permissible is too large for some applications.

In view of the above, the single sector compensator

illustrated in Fig. 3 will in general be found adequate and suitable for use with wave guides of such size that they will support not more than 40 to 50 modes of propagation at the frequencies with which they are to be employed.

For larger guides i.e. guides capable, for example, of supporting two or three hundred modes of propagation at the frequencies to be used, a three sector dielectric compensator as illustrated in the cross-sectional diagram of Fig. 4 can be employed.

This arrangement comprises guide 30 having therein a center sector 20 having an angle θ_1 and two outer sectors 22 and 24, respectively, on opposite sides of center sector 20, each having an angle θ_2 and each being at an angle of ψ with respect to the center sector as shown.

The TE_{01} mode will be decoupled from the TM_{11} mode if the following relation is satisfied.

$$\delta = \frac{1.5295}{\left(2 \cos \psi \sin \frac{1}{2} \theta_2 + \sin \frac{1}{2} \theta_1\right)} \frac{a}{b} \quad (3)$$

Having determined δ and

$$\frac{a}{b}$$

to satisfy Relation 3, decoupling of the TE_{01} mode from all modes of the TE_{2m} , TE_{3m} , TE_{2m} or TM_{3m} families can be realized if the further Relations 4 and 5 given immediately following, are also satisfied.

$$2 \cos 2\psi \sin \theta_2 + \sin \theta_1 = 0 \quad (4)$$

$$2 \cos \psi \sin \frac{3}{2} \theta_2 + \sin \frac{3}{2} \theta_1 = 0 \quad (5)$$

To facilitate the design of three-sector compensators, Equations 4 and 5 have been solved numerically for θ_2 and ψ in terms of θ_1 for each ten degree interval between zero and 120 degrees, which appears entirely sufficient for cases of practical interest.

In addition, the auxiliary quantity represented by Relation 6 given below, has also been computed, and designated f_1 . f_1 is, of course, the denominator of the first term of the right side of Relation 3, above.

These quantities are tabulated in Table I, below, and are the basis for the curves of Figs. 6 and 7 of the accompanying drawings. Curves 46 and 48 of Fig. 6 show values of ψ and θ_2 corresponding to various values of θ_1 , respectively, and curve 50 of Fig. 7 shows values of f_1 corresponding to various values of θ_1 .

$$f_1 = 2 \cos \psi \sin \frac{1}{2} \theta_2 + \sin \frac{1}{2} \theta_1 \quad (6)$$

Table I

θ_1	θ_2	ψ	f_1
Degrees	Degrees	Degrees	
0	0	72.00	0
10	6.15	72.06	0.12020
20	12.12	72.26	0.23801
30	17.72	72.60	0.35093
40	22.73	73.14	0.45632
50	26.90	73.92	0.55147
60	30.00	75.00	0.63397
70	31.86	76.44	0.70233
80	32.47	78.27	0.75647
90	31.92	80.51	0.79777
100	30.44	83.18	0.82840
110	28.28	86.31	0.85057
120	25.66	89.75	0.86796

To design a three sector compensator with given values of a/b and δ the auxiliary quantity f_1 is determined from Relation 3, i. e.

$$f_1 = \frac{1.5295}{\delta} \frac{a}{b} \quad (7)$$

The value of f_1 thus determined is located on curve 50 of Fig. 7 and the corresponding value of θ_1 is noted.

Corresponding values of ψ and θ_2 are then read from curves 46 and 48 of Fig. 6, respectively.

For values of θ_1 not greater than 20 degrees the following simplified Relations 8, 9 and 10 may be used with reasonably accurate results.

$$\theta_1 = \frac{126.8}{\delta} \frac{a}{b} \text{ degrees} \quad (8)$$

$$\theta_2 = 0.618 \theta_1 \text{ degrees} \quad (9)$$

$$\psi = 72 \text{ degrees} \quad (10)$$

It should be noted that the precision with which θ_1 , θ_2 and ψ are individually determined is not of critical importance since reasonably small couplings to the TE_{21} and TE_{31} modes are acceptable.

However, the coupling of the TM_{11} mode to the TE_{01} mode should be made as nearly zero as possible, so that Relation 3 should be satisfied with the greatest possible precision.

By way of a specific numerical example, for a conversion loss into the TE_{12} mode (which is the worst remaining spurious mode with this type of compensator) not greater than 0.1 decibel in a seven-eighths-inch guide at 5.4 millimeters, the minimum bending radius should be 7.39 inches and δ should be 0.143 (which is readily obtained with foam dielectrics). Angles θ_1 , θ_2 and ψ are, respectively, 60 degrees, 30 degrees and 75 degrees. (60 degrees is, for the majority of practical applications, a maximum value of the angle θ_1 since at larger values the outer sectors are counteracting the effect of the central sector with respect to decoupling the mode TM_{11} so that the dielectric losses are increased beyond those normally acceptable.) Assuming a loss tangent of 2×10^{-4} , the dielectric loss in a 90 degree bend is substantially 0.12 decibel.

As a second specific numerical example, for the same conversion loss as above, for a two-inch guide at 5.4 millimeters, the minimum bending radius should be 11.92 feet, and if δ is 0.033, the angles θ_1 , θ_2 and ψ should be 27.6 degrees, 16.4 degrees and 72.5 degrees, respectively. Assuming a loss tangent of 5×10^{-5} the dielectric loss in a 90 degree bend is substantially 0.25 decibel.

A possible third form of compensator for insertion within the bend of a wave guide 40 is illustrated in Fig. 5 and comprises an annular sector 42 of thickness t having an angle θ , and placed on the inside of the bend and symmetrically located with respect to the plane of the bend. Since, as above-mentioned, this compensator couples the TE_{01} mode to the higher circular modes TE_{02} , TE_{03} , etc., it is of practical interest only for guides of sufficiently small diameter that these higher circular modes are cut off by the guide itself. For example, a guide diameter of $\frac{7}{16}$ inch at 5.4 millimeters would be suitable. If t is small with respect to the radius a of wave guide 40, i.e. if, for example, it does not exceed

$$\frac{a}{3}$$

then the decoupling condition for the TM_{11} mode with respect to the TE_{01} mode is expressed by the following relation.

$$\frac{t}{a} = \left[\frac{0.321}{\delta \sin \frac{1}{2} \theta} \cdot \frac{a}{b} \right]^{1/3} \quad (11)$$

While of limited application, this form of mode compensator is very simple and economical, where it can be appropriately employed.

In Figs. 8 and 9 a plan and end view, respectively, of a further specific arrangement of the invention are illustrated in which a spurious mode suppressor or compensator is provided in a straight section of guide at one end of a plane curved section or bend of guide, the compensator reconverting to the TE_{01} mode energy the mixture of TE_{01} and TM_{11} mode wave energy emerging from the

output end of a bend, resulting from the application of TE₀₁ mode energy at the input or other end of the bend.

The wave guide bend 80 has a length l_1 along its longitudinal axis and the compensator 84 comprises a semi-cylindrical dielectric member assembled in a straight section of wave guide 82 attached to the "output" end of the bend 80, the compensator having a length l_2 . The compensator element 84 should be in the lower half of section 82, as shown in Figs. 8 and 9. The diametral surface of the compensator element 84 must be perpendicular to the plane of the bend 80, i.e. perpendicular to the plane which includes the longitudinal axis and the radius of curvature of the curved section or bend 80.

The condition that all the power be reconverted back to TE₀₁ mode wave energy at the output of the compensator, i.e. at the right end of member 84 for the specific case illustrated in Fig. 8, is as follows:

$$\frac{1.1595l_1a}{\lambda b} - 0.12066\beta\delta l_2 = 0 \quad (12)$$

By rearrangement the condition of Equation 12 becomes

$$l_2\delta = 1.5295l_1\frac{a}{b} \quad (13)$$

While illustrated in Fig. 8 as applicable for the direction of transmission from the curved to the straight portions of wave guide the action of the combination of Fig. 8 is equally effective for transmission in the opposite direction. Also the member 84 and the straight section of wave guide enclosing it may be divided into two portions, one portion being placed at each end of the curved section of wave guide or the bend 80. So long as the total length of the two portions taken together (l_2) satisfies the Relation 13 above, it is immaterial whether the portions are of equal or unequal lengths. A particular advantage of the arrangement of Fig. 8 is the ease with which the total length l_2 of the compensating member 84, (or of its two parts, if a portion is located at each end of the bend) can be adjusted. The arrangement of Fig. 8, unlike the normal mode arrangement mentioned above, is not frequency sensitive and is therefore inherently an extremely broad band arrangement.

Numerous and varied other arrangements within the spirit and scope of the principles of the present invention can readily be devised by those skilled in the art. The above-described arrangements are illustrative, but by no means cover exhaustively all possible arrangements clearly within said scope.

What is claimed is:

1. A uniconductor, tubular wave guide including a plane curved portion or bend and means for compensating for the conversion of TE₀₁ mode microwave energy into other modes during transmission through said bend, said means comprising a dielectric member disposed in and extending longitudinally through a substantial portion of said plane curve or bend, the cross-section of said dielectric member being of substantially sectoral shape and symmetrically positioned with respect to the plane of said curved portion or bend, said member being situated solely on the side of said wave guide nearer the center of curvature of said bend.

2. A mode compensated, uniconductor, tubular, wave guide comprising a plane curved portion or bend, a dielectric member extending longitudinally throughout said bend, the cross-section of said dielectric member being of sectoral shape extending from the longitudinal center line of said wave guide to the inner surface thereof and subtending an arc not exceeding 150 degrees, said arc being symmetrically positioned with respect to the plane of curvature of said plane curved portion or bend and being situated on the side of said longitudinal axis nearer the center of curvature of said bend.

3. The arrangement of claim 2 wherein the angle sub-

tended by said dielectric sector is substantially 144 degrees.

4. The arrangement of claim 2 wherein the angle subtended by said dielectric sector is not greater than sixty degrees and said guide includes second and third sectoral dielectric members each subtending an angle of substantially 60 percent of that of said first sector, said second sector being on one side of said first sector, said third sector being on the other side of said first sector, said second and third sectors being at an angle not exceeding 75 degrees with respect to said first sector, center to center, and extending from the longitudinal axis of said wave guide bend to the inner surface of said guide.

5. A mode compensated, uniconductor, tubular, wave guide comprising a plane curved portion or bend, an annular, sectoral, dielectric member having a thickness less than the radius of said guide assembled symmetrically with respect to the plane of the bend against the side of said guide nearer the center of curvature of said bend and extending longitudinally throughout said bend.

6. The arrangement of claim 1 wherein the permittivity of the dielectric member is $1+\delta$, a is the radius of the guide, b is the radius of curvature of the bend, t is the thickness of the dielectric member along a radius of the guide and is no greater than one-third of said radius, and θ is the angle subtended by the dielectric member, the overall arrangement conforming substantially to the relation

$$\left[\frac{t}{a} = \frac{0.321}{\delta \sin \frac{1}{2}\theta} \cdot \frac{a}{b} \right]^{1/3}$$

7. A mode compensator for a plane curved section or bend of single, tubular conductor, wave guide, said compensator comprising a sector of dielectric having a permittivity of $1+\delta$, said sector extending longitudinally throughout said bend and symmetrically with respect to the plane of said bend on the side of said wave guide nearer the center of curvature of the bend, said dielectric section conforming to the relation

$$\delta = \frac{1.5295}{\sin \frac{1}{2}\theta} \cdot \frac{a}{b}$$

where θ is the angle subtended by said sector, a is the radius of said wave guide and b is the radius of curvature of said bend.

8. A mode suppressor or compensator for eliminating the conversion of TE₀₁ mode microwave energy into unwanted modes of microwave energy while being transmitted through a curved portion of a round wave guide, said suppressor comprising a first sector of dielectric material extending throughout said curved portion of wave guide from the longitudinal center line of said portion of wave guide to the inner surface thereof, said sector being directed toward the center of curvature of said portion of wave guide, said sector subtending an angle of between 10 and 60 degrees, symmetrically positioned with respect to the plane of curvature of said portion of wave guide, and second and third sectors of dielectric material extending throughout said curved portion of wave guide and from the longitudinal center line of said portion of wave guide to the inner surface thereof on opposite sides of said first sector, each of said second and third sections being at an angle, center to center with respect to said first sector, of between 72 and 75 degrees, said second and third sectors each subtending an angle of between 50 to 60 percent of the angle subtended by said first sector, said suppressor conforming substantially to the relation

$$\delta = \frac{1.5295}{\left(2 \cos \psi \sin \frac{1}{2}\theta_2 + \sin \frac{1}{2}\theta_1 \right)} \cdot \frac{a}{b}$$

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where $1+\delta$ is the permittivity of the dielectric material, θ_1 is the angle subtended by said first sector, θ_2 is the angle subtended by each of said second and third sectors, ψ is the angle center to center between said first sector and each of said second and third sectors, a is the radius of said wave guide and b is the radius of curvature of said curved portion of wave guide.

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