Aug. 23, 1966 R. H. TURRIN 3,268,902

DUAL FREQUENCY MICROWAVE APERTURE-TYPE ANTENNA PROVIDING SIMILAR RADIATION PATTERN ON BOTH FREQUENCIES

Filed Dec. 5, 1963 3 Sheets-Sheet 1

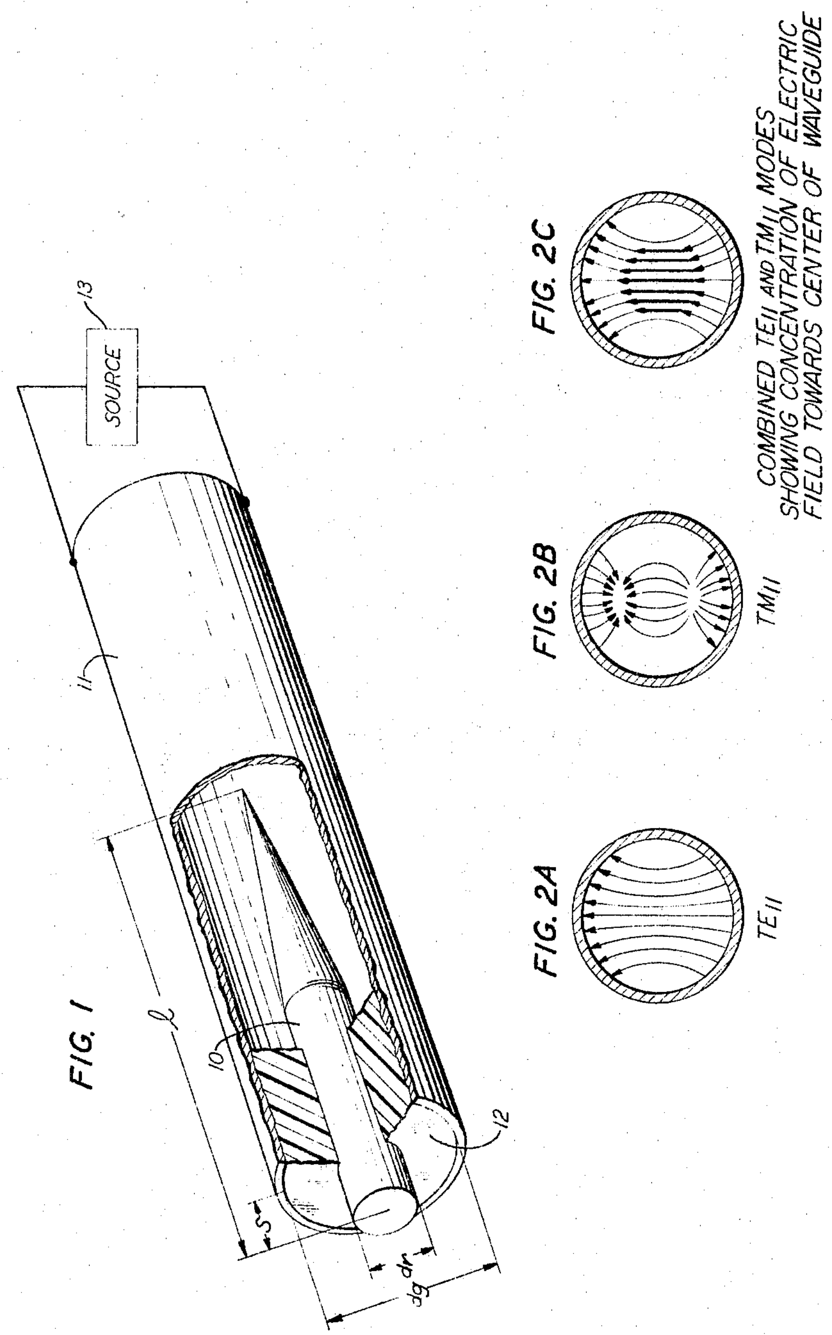

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FIG. 3

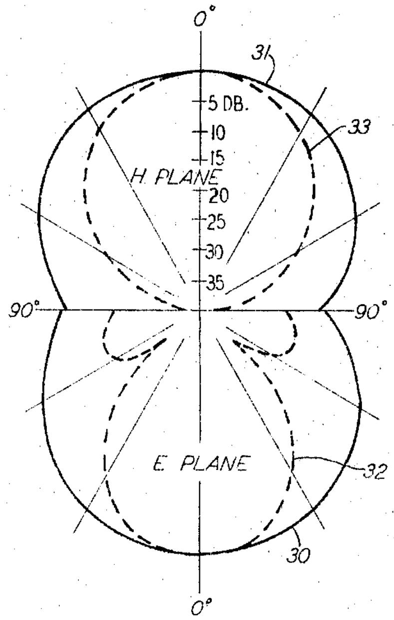


FIG. 4

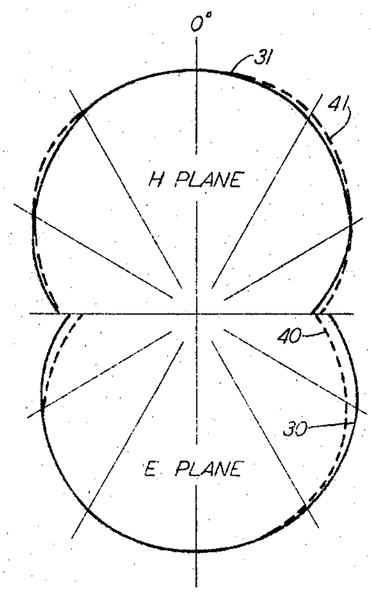


FIG. 5

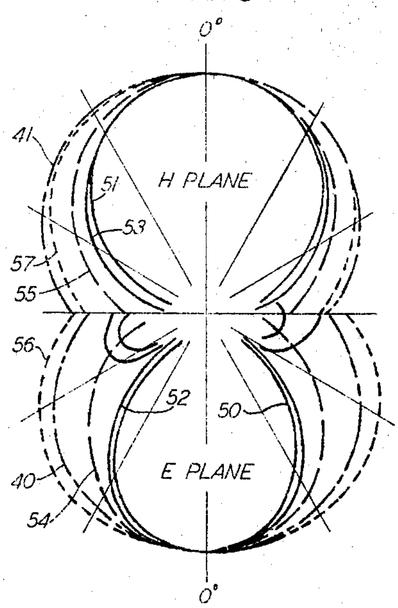


FIG. 6

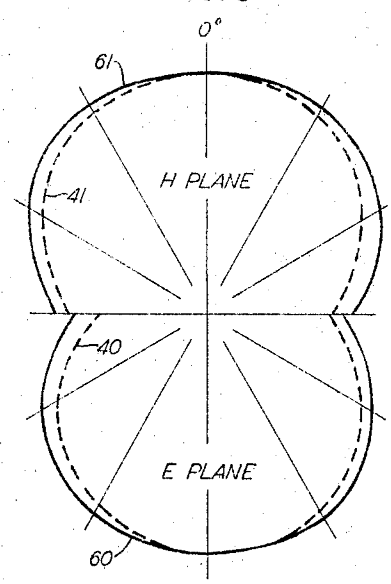
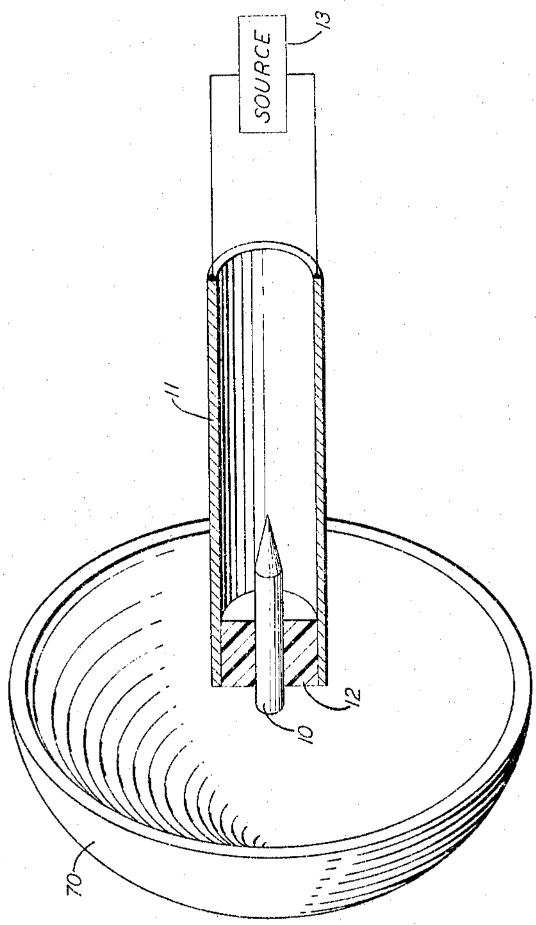


FIG. 7



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DUAL FREQUENCY MICROWAVE APERTURE-TYPE ANTENNA PROVIDING SIMILAR RADIATION PATTERN ON BOTH FREQUENCIES

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This invention relates to microwave antennas and more particularly to dual frequency microwave antennas of the small aperture type.

Frequently in the field of microwave communication it is desirable to utilize a single antenna structure for radiating and directing two signals occupying separate and distinct frequency bands. For example, in cross-country microwave systems which utilize many repeater stages at spaced intervals along the transmission path, one frequency may be utilized for signals transmitted in one direction and another for receiving signals transmitted in the reverse direction. In addition, it is also desirable to transmit the signals at both frequencies with orthogonal polarized fields. By so doing, it is possible to achieve a twofold increase in information transmission by utilizing the well known null property of cross-polarized plane wave fields. In such systems it is understandable that if a single antenna can be utilized for both frequencies and for both planes of polarization, substantial economic savings can be enjoyed.

It is therefore a general object of the present invention to provide a dual frequency microwave antenna.

A fundamental problem encountered by one attempting to utilize a single small-aperture antenna for radiating directly or for illuminating a large reflector at two separated frequencies is the difference in the radiation pattern of the antenna at the two frequencies. In general, the beamwidth of the radiation pattern of an aperture-type antenna is inversely related to frequency. Thus, for a small-aperture antenna such as an open-ended waveguide, the radiation pattern becomes narrower as the frequency of the radiated energy becomes higher. This difference in radiation pattern at the two frequencies is undesirable.

It is, therefore, a further object of the present invention to provide a dual frequency microwave antenna having substantially the same radiation pattern over two separated frequency ranges.

It is yet another object of the present invention to provide a primary feed for a large aperture-type antenna capable of illuminating the large aperture to the same extent over two separated frequency ranges.

The above objects are accomplished in accordance with the present invention by decreasing the effective area of a radiating aperture at the higher of two frequencies while retaining the effective aperture size at the lower frequency. In general, this can be accomplished by concentrating the wave energy at the higher frequency in the center region of the aperture. In a preferred embodiment this is done by loading the aperture with a coaxially located rod of dielectric material. The position and dimensions of the dielectric rod determine the shape of the high frequency radiation pattern.

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

FIG. 1 is a pictorial view, partially broken away, of one embodiment of the present invention;

FIG. 2A is a cross-sectional view of a circular waveguide showing the electric field lines in the TE_{11} wave mode;

FIG. 2B is a cross-sectional view of a circular waveguide showing the electric field lines in the TM_{11} wave mode;

FIG. 2C is a cross-sectional view of a circular waveguide showing the combined TE_{11} and TM_{11} electric field lines;

FIG. 3 is a graphical representation of the radiation pattern of an unloaded circular waveguide aperture at two frequencies;

FIG. 4 is a graphical representation of the radiation pattern of the embodiment of FIG. 1 at the same two frequencies;

FIG. 5 shows, in graph, the effect of a change in the diameter of rod **10** of FIG. 1 on the radiation pattern;

FIG. 6 shows, in graph, the effect of the position of rod **10** of FIG. 1 on the radiation pattern; and

FIG. 7 is a pictorial view, partially broken away, of the embodiment of FIG. 1 utilized as a primary feed in a parabolic reflector-type antenna.

Referring more particularly to the drawings, FIG. 1 is a partially broken away pictorial view of a preferred embodiment of the present invention. A cylindrical dielectric rod **10** having a diameter d_r and length l is coaxially located within a hollow, conductively bounded section of cylindrical waveguide **11** having an inside diameter d_g. In general, the dielectric constant of rod **10** is significantly greater than that of the medium filling guide **11**. For example, if the medium filling guide **11** is air which has a dielectric constant near unity, rod **10** is preferably formed of a material having a dielectric constant of two or greater. Rod **10** is held in position by an annular member **12** of polyfoam, or other low-loss dielectric material having a dielectric constant substantially equal to that of the medium filling the remainder of guide **11**—in the exemplary case, unity. Rod **10** is tapered at the end thereof extending within guide **11**. The other end of rod **10** is blunt and extends a distance s out of the end of guide **11**. As will be discussed in greater detail hereinbelow the distance s is generally quite small with respect to the overall length l.

When used as a transmitting antenna or as a primary feed for a reflector-type antenna, electromagnetic wave energy from a source or transmitting device **13**, shown in simplified block diagram form, is fed into the end of guide **11** most distant from rod **10** in the TE_{11} wave mode. This energy can be applied through a coaxial line-to-waveguide transducer, through a waveguide transformer section or through another length of circular waveguide, depending upon the nature of the transmission means connecting guide **11** to the source. On the other hand, if the device is being used as a receiving antenna, it is obvious that the received energy can be extracted from the end of guide **11** for delivery to the input of the receiver by the same transmission means.

At this point it may be helpful, in understanding the operation of the invention, to consider the radiation characteristics of an unloaded, open-ended, circular waveguide (i.e., a guide with no dielectric rod). When such a guide acts as a radiator for wave energy propagating therethrough in the dominant TE_{11} wave mode, the radiation patterns are as shown in FIG. 3. When the frequency of the radiated energy is slightly above the cutoff frequency of the guide for the TE_{11} wave mode, the resulting radiation pattern is that shown by curves **30** and **31** in the electric and magnetic planes, respectively. As the frequency of the radiated wave energy is increased, the radiation pattern becomes narrower, as indicated by broken line curves **32** and **33** of FIG. 3.

With the above facts in mind, the question arises, how to obtain a radiation pattern at the higher frequency which has substantially the same shape and beamwidth as the radiation pattern at the lower frequency. Obviously, this can be accomplished by physically scaling down the size of the waveguide aperture when utilized at the higher frequency so that its diameter is proportionately smaller for this shorter wavelength. In most cases, however, it is impractical to physically change the aperture dimension, especially in view of the fact that such structure is generally mounted at the top of a high tower or other comparatively inaccessible point.

In accordance with the present invention, an equivalent reduction in aperture size is accomplished without physically varying the size of the waveguide aperture by mode conversion effects. In FIG. 2A there is shown a cross-sectional view of a circular waveguide such as guide **11** of FIG. 1. The arrows represent the electric field configuration in the guide for wave energy propagating in the TE_{11} wave mode. If a smaller guide were utilized, it is clear that the field configuration would have exactly the same shape, merely reduced in scale. If, however, a portion of the total wave energy is caused to propagate in the TM_{11} wave mode, the effective aperture size can be substantially decreased. FIG. 2B is a cross-sectional view of the same circular waveguide supporting wave energy in the TM_{11} wave mode. Again, the arrows represent the electric field configuration for such wave mode. If the two field patterns are combined, the resulting field configuration is somewhat as shown in FIG. 2C.

As indicated in FIG. 2C, the electric fields for the two modes will cancel to a certain extent in the regions near the guide wall but will be enhanced in the region near the center of the guide. The degree of cancellation and enhancement, of course, depends upon the relative magnitudes of the fields in each of the two modes. The result, however, is that the wave energy is, to a large extent, confined to the center of the guide, just as if the size of the aperture itself had been decreased. By adjusting the relative phase and magnitude of the wave energy in the TM_{11} wave mode, the radiation pattern of the guide can be made much broader.

Returning to the embodiment of FIG. 1, one method of inducing a partial conversion of the energy in the TE_{11} wave mode to the TM_{11} wave mode is by utilizing dielectric rod **10**. As will be discussed in greater detail hereinbelow, the dimensions and position of rod **10** within guide **11** determine the phase and magnitude of the TM_{11} wave energy, and consequently the shape of the radiation pattern of the embodiment. Since, for a given diameter circular waveguide, the cutoff frequency of TM_{11} wave energy is more than twice that of TE_{11} wave energy, it is a simple matter to proportion the guide diameter so that the energy in the TM_{11} wave mode is propagated only at the higher and not at the lower of the two frequencies of operation. In this manner, the low frequency radiation pattern of the device is not affected by rod **10**, whereas the high frequency radiation pattern is broadened.

Although the above description is in terms of the electric fields inside a circular waveguide, it is equally applicable to the magnetic fields. That is, the magnetic fields in the TE_{11} and TM_{11} wave modes also cancel in the regions near the guide wall and add in the center region of the guide in much the same manner. This results in a broadening of the radiation pattern in the magnetic or H plane at the high frequency which can be made to correspond to the normally broad pattern at the low frequency.

Several experimental models of the embodiment of FIG. 1 were constructed and operated. These devices were designed for low frequency operation at 6.175 kilomegacycles per second, and for high frequency operation at 11.2 kilomegacycles per second. In these structures, the inside diameter d_g of guide **11** was 1.75 inches. The radiation pattern for this open-ended circular waveguide at the low frequency when radiating energy propagated in the TE_{11} wave mode is shown in the graph of FIG. 3. The solid curve **30** represents the radiation pattern measured in the electric field or E plane, whereas curve **31** represents the radiation pattern in the magnetic field or H plane. Curves **30** and **31** represent the "unloaded" condition, that is, without a dielectric rod. In the graph of FIG. 3 as well as those of FIGS. 4, 5 and 6, the curves are shown on a normalized scale, with the maximum radiation intensity equated to zero decibels.

At the high frequency, the radiation pattern for the unloaded guide is shown by curves **32** and **33**. Curve **32** represents the E-plane pattern and curve **33** represents the pattern in the H plane. As mentioned above, it is readily seen that the high frequency radiation patterns are considerably narrower than those at the lower frequency.

In order to broaden the high frequency radiation patterns while leaving the low frequency radiation pattern substantially unaffected, dielectric rod **10** was disposed within guide **11** in the manner described in connection with FIG. 1. A dielectric rod having a diameter d_r of 0.5 inch, a length l of 3 inches, and a taper of 1.3 inches was utilized. This rod was fabricated with Teflon having a dielectric constant of approximately 2.0 over the frequency range of operation. Annular spacing member **12** was fabricated of polyfoam having a dielectric constant substantially equal to 1.0. It was found that this rod, when inserted into guide **11** to a point where s equalled 0.25 inch, resulted in a radiation pattern at the high frequency substantially identical to that of the unloaded guide at the low frequency. It was further found that the presence of rod **10** in guide **11** did not significantly alter the low frequency radiation pattern.

FIG. 4 is a graphical representation of the results of the above-mentioned findings. Curves **30** and **31** again represent the low frequency radiation pattern of the device sent the low frequency radiation pattern of the device in the E and H planes, respectively. As mentioned above these curves were substantially identical regardless of whether rod **10** was in place or not in place. Curves **40** and **41** represent the high frequency pattern in the E and H planes, respectively. Curves **40** and **41**, when compared with curves 32 and 33 of FIG. 3 illustrate the beam broadening effect of dielectric rod **10**. It is readily seen from the similarity of curves **30** and **40** and curves **31** and **41** that by providing guide **11** with a dielectric rod load the radiation patterns can be made substantially identical for two widely separated frequencies.

It is evident that in the embodiment of FIG. 1 there are several variable parameters. First the diameter of rod **10** can be varied in order to vary the radiation pattern of the device. In general the radiation pattern at the low frequency remains substantially unchanged in the presence of a dielectric rod of any diameter. On the other hand the high frequency radiation pattern in general produces a broadening in beamwidth for increasing rod diameter. FIG. 5 shows the measured radiation patterns for the high frequency for various rod diameters. In each case the distance s was maintained at 0.25 inch. Curves **50** and **51** represent the radiation pattern for the unloaded guide. Curves **52** and **53** are the patterns utilizing a rod having a diameter of 0.25 inch. Curves **54** and **55** and curves **40** and **41** represent the radiation patterns for rods having diameters of 0.375 and 0.50 inch respectively. Curves **56** and **57** represent the pattern resulting from a 0.75 inch diameter rod.

With regard to curves **40**, **41**, **56** and **57**, it is seen that the E-plane pattern for the 0.50 inch rod is slightly narrower than that for the 0.75 inch rod, whereas in the H plane, the 0.75 inch rod produced the narrowerer pattern.

As mentioned above in making the measurements reproduced in FIG. 5 the distance s which rod **10** protrudes from the end of guide **11** was maintained at 0.25 inch. This distance s is also a parameter which can be varied to change the radiation pattern of the device at its high frequency. FIG. 6 is a graphical representation of the radiation pattern of the embodiment of FIG. 1 utilizing a rod of 0.5 inch diameter. Curve **40** again represents the E-plane pattern produced with s equal to 0.25 inch.

Curve 41 represents the H-plane pattern for the same value of s. Curves 60 and 61 represent the patterns for s equal to zero in the E and H planes respectively. It is seen therefore that some degree of adjustment is provided by moving rod 10 in or out of guide 11. As rod 10 is moved more and more into guide 11 so that s becomes less and less the radiation pattern of the device broadens.

In addition to varying the diameter of rod 10 and the position thereof, one can also vary the length l of the rod and the length of the taper. In general, the length of the taper with respect to the total length l of the rod has no significant effect on the radiation patterns of the device. On the other hand, the length l of the rod does have an effect on the high frequency radiation patterns. It was found that a 7 inch rod yielded a high-frequency beamwidth several percent narrower than that produced with a 3 inch rod.

The dielectric loaded small-aperture antenna of FIG. 1 can also be utilized as a primary feed for large-aperture antennas of the reflecting or refracting type. In FIG. 7 there is shown in a partially broken away pictorial view, a reflecting paraboloid 70 of the type well known in the art. Paraboloid 70 is fed by means of guide 11 containing dielectric rod 10. Again, corresponding numerals have been carried over from FIG. 1 to designate corresponding structural elements.

The operation of the embodiment of FIG. 7 is substantially identical to other paraboloid or "dish" reflectors well known in the art except that the means employed for feeding the antenna allows the reflector to be illuminated to the same degree at two separated frequency bands. That is, in accordance with the principles explained in connection with the embodiment of FIG. 1, substantially the same radiation pattern is produced by the feed at both the low and high frequency bands. This results in increased high-frequency gain for the large-aperture antenna.

It is understood that the above-described arrangements are merely illustrative of the application of the principles of the present invention. It is obvious that by appropriate design techniques other arrangements including those utilizing other than circular waveguides or rods and other beam focusing means may be devised by those skilled in the art without departing from the spirit and scope of the present invention.

What is claimed is:

1. An aperture-type antenna comprising, in combination, a hollow conductively bounded waveguide of circular cross section having an input end and an output end, means for applying electromagnetic wave energy of at least two separate frequencies to said input end of said guide in the TE_{11} wave mode, means for radiating wave energy from said output end of said guide at both said frequencies with substantially the same radiation pattern, said latter means comprising a dielectric rod coaxially aligned with said guide and extending from a point within said guide to beyond the output end of said guide, said rod having a dielectric constant and a diameter such that said guide, over the interval coextensive with said rod,

is supportive of wave energy at the lower of said frequencies exclusively in the TE_{11} mode of wave propagation and, simultaneously, is supportive of wave energy at the higher of said frequencies in both the TE_{11} and the TM_{11} modes of wave propagation.

2. The antenna according to claim 1 wherein said rod diameter is less than one-half said guide diameter.

3. The antenna according to claim 1 including additional means for focusing said radiated wave energy.

4. A dual frequency microwave antenna comprising, in combination, a hollow conductively bounded cylindrical waveguiding section, means for applying electromagnetic wave energy of first and second frequency ranges to one end of said section in the TE_{11} wave mode, means for converting the wave energy at the higher of said frequency ranges to the TM_{11} wave mode while leaving the wave energy at the lower of said frequency ranges exclusively in the TE_{11} wave mode, and means for radiating said energy from the other end of said section.

5. The antenna according to claim 4 wherein said mode conversion means comprises a dielectric rod coaxially disposed within said section at said other end thereof.

6. The antenna according to claim 4 including additional means for focusing said radiated wave energy.

7. A dual frequency aperture-type antenna comprising, in combination, a hollow conductively bounded waveguiding section of circular cross section capable of supporting propagating electromagnetic wave energy over at least two separated frequency bands, means for concentrating the wave energy of the higher of said two frequency bands towards the center of said waveguiding section comprising a dielectric rod coaxially disposed within said section at one end thereof, said rod having a dielectric constant substantially greater than the medium filling the remainder of said section and having a diameter substantially less than the diameter of said section, said dielectric constant and the diameter of said rod being further selected such that at the lower of said frequency bands said waveguide is supportive exclusively of TE_{11} mode wave energy over the portion of said section coextensive with said rod, and, simultaneously, at the higher of said frequency bands is supportive of both the TE_{11} and the TM_{11} modes of wave propagation.

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