June 26, 1956 C. POLK 2,752,577

WIDE BAND COAXIAL TRANSMISSION LINE

Filed Dec. 26, 1951

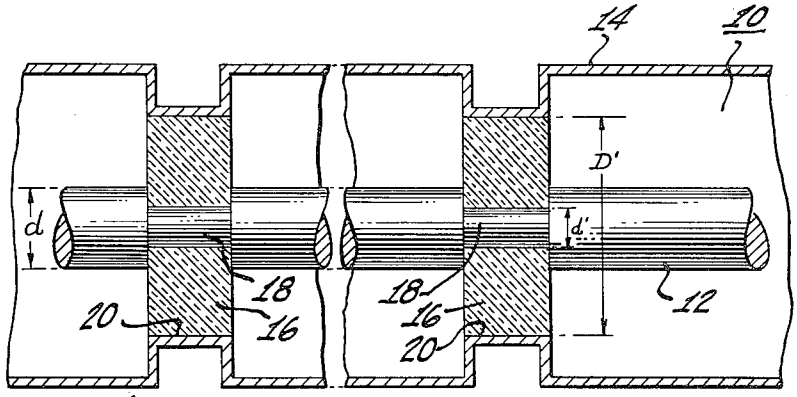


Fig. 1.

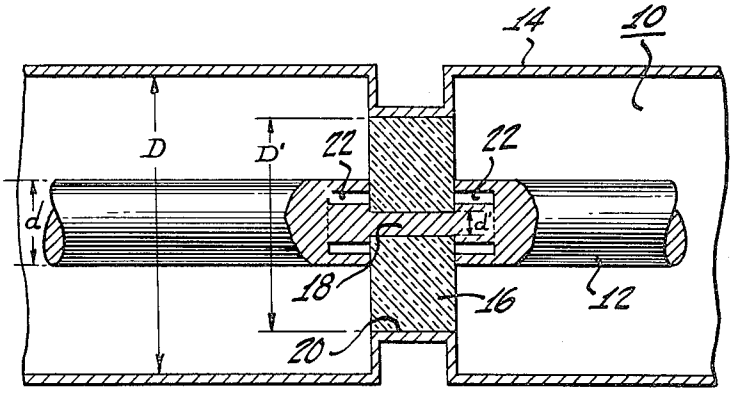


Fig. 2.

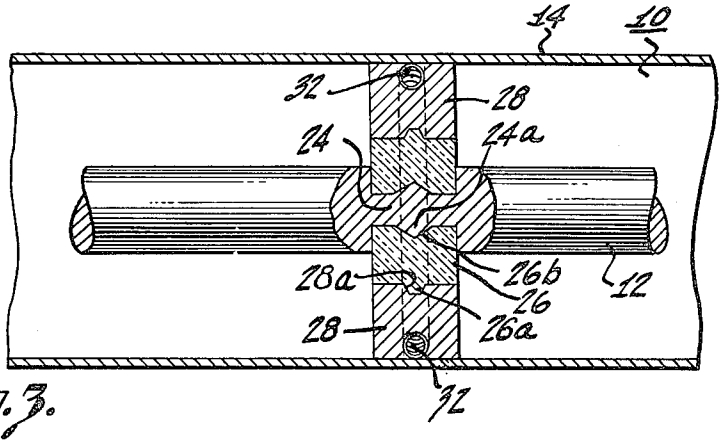


Fig. 3.

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United States Patent Office 2,752,577 Patented June 26, 1956

2,752,577

WIDE BAND COAXIAL TRANSMISSION LINE

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Application December 26, 1951, Serial No. 263,257

9 Claims. (Cl. 333—96)

The present invention is related to coaxial transmission lines, and particularly to so-called bead supported coaxial lines.

The inner conductor of a coaxial line must be suitably supported coaxially with the outer conductor. For low losses, at very high operating frequencies, an air or gas dielectric is desirable rather than a solid dielectric. It is common in coaxial lines designed for high frequency operation with low losses, to use spaced dielectric beads for coaxially supporting the inner conductor. In such instances the major portion of the dielectric is air or other gas. However, the presence of the beads cause wave reflections at the interfaces between the gaseous dielectric and the bead dielectric. These reflections may be reduced by undercutting (reducing the diameter) of the inner conductor or alternatively overcutting (increasing the diameter) of the inner surface of the outer conductor, or both. When the inner conductor is properly undercut or the outer conductor properly overcut, or both, the characteristic impedance of the line may be maintained the same in the air and in the bead dielectric and the reflections are reduced.

However, at very high frequencies, a further problem arises from the fact that the coaxial transmission line is usually operated in the dominant mode having radial electric vectors. By the term dominant mode is meant that mode of propagation which has the longest cut-off wavelength (lowest cut-off frequency). The next to the dominant mode has the next longest cut-off wavelength. As the frequency of energy applied to a transmission line is increased from the lowest toward higher frequencies, first the dominant mode is propagated and then the next to the dominant mode is propagated, and thereafter third or fourth higher order modes. In coaxial transmission lines the dominant mode is the TEM mode with zero frequency cut-off. The next to the dominant mode is the $TE_{1,1}$ mode, with cut-off frequency corresponding, approximately, to a free space wavelength equal to the circumference at the arithmetic mean diameter of the two coaxial conductors. Thus the cut-off wavelength for the next to the dominant mode is

$$\pi\frac{(D_0+D_1)}{2}$$

where D_0 and D_1, are respectively the inner and outer conductor diameters. If the next to the dominant ($TE_{1,1}$) mode is excited, the loss of energy in the desired TEM transmission mode is increased. The use of dielectric bead supports decreases the cut-off frequency of the next to the dominant ($TE_{1,1}$) mode, inside the dielectric bead, thereby limiting the useful frequency range over which the line may be employed. For example, the cut-off frequency for the next to the dominant mode in proposed RMA standard 50 ohm, 6⅛" outside diameter coaxial line is about 895 MCS (megacycles per second). Therefore the usefulness of this standard line is greatly impaired at frequencies much over 895 MCS, but the

line may be used efficiently for frequencies less than to frequencies nearly as great as 895 MCS. However, with teflon beads and the outer conductor overcut to maintain a constant characteristic impedance in the bead dielectric, the next to the dominant mode cut-off frequency is reduced to 472 MCS within the beads. In practice, this means that the line cannot be successfully employed at frequencies much over 472 MCS.

It is an object of the present invention to extend the useful frequency range of coaxial lines.

Still another object of the invention is to provide a bead supported coaxial line in which the cut-off frequency of the first higher order mode (or next to the dominant mode) in the dielectric bead section is higher than that for the next to the dominant mode in the air filled section.

Another object of the invention is to provide a coaxial line for which the cut-off frequency of the next to the dominant mode is at least as great in a dielectric filled portion as in an air filled portion.

A still further object of the invention is to arrange that the cut-off frequency of the next to the dominant mode in a dielectric bead of a bead supported coaxial line is equal to or greater than that in the gas filled portion of the line.

Still another object of the invention is to arrange that in a dielectric filled portion of a coaxial line the cut-off frequency of the next to the dominant mode be equal to or greater than, and the characteristic impedance for the dominant mode of a coaxial line to be the same as, respectively, the cut-off frequency of the dominant mode and the characteristic impedance of an air filled portion of the same line; and particularly for this cut-off frequency in the bead to be greater than or the same as that in the air filled portion of the bead supported line while the characteristic impedances at the same time are equal in the bead portion and the air-filled portion of the line.

According to the invention, in a coaxial line having a dielectric-filled and air-filled portions, the outer conductor is undercut at the dielectric-filled portion sufficiently to increase the cut-off frequency for the next to the dominant mode to be at least as great as that in the air-filled portion. Sometimes it is preferred that the cut-off frequency of the next to the dominant mode in the dielectric-filled portion of the coaxial line be equal to and sometimes greater than that in the air-filled portion. Further the inner and outer diameters of the undercut line portion are related substantially in the ratio which makes the characteristic impedance of the dielectric-filled portion of the line substantially equal to that of the air-filled portion.

The foregoing and other objects, advantages, and novel features of the invention will be more fully apparent from the following description when taken in connection with the accompanying drawing in which like reference numerals refer to like parts and in which:

Fig. 1 is a longitudinal cross-sectional view of a bead-supported coaxial line having undercut inner and outer conductors according to the invention;

Fig. 2 is a longitudinal cross-sectional view of the line of Fig. 1 in which the invention is employed in conjunction with known reflection reducing means; and

Fig. 3 is a longitudinal cross-sectional view of a modification of the embodiment of Fig. 1.

Referring to Fig. 1, a coaxial line **10** has an inner conductor **12** of diameter *d* and an outer conductor **14** of inside diameter D. The inner conductor **12** is coaxially supported by dielectric beads **16**. The inner conductor **12** is undercut at a portion **18** of diameter *d'*. The outer conductor **14** is undercut at a portion **20** of inside diameter D'. The $TE_{1,1}$ cut-off frequencies for the air-filled

portion and of the dielectric-filled (beaded) portion of the line may be computed from known formulas. It may then be shown that the cut-off frequency f_c' of the next to the dominant mode for the dielectric filled portion **18**, **20** of the line **10** may be increased to be equal to or greater than that f_c for the air filled portion by satisfying the following approximate formula:

$$f_c' = \frac{2K_s c}{\pi D'(1+d'/D')\sqrt{\epsilon}} \geq f_c$$

where K_s is a correction factor slightly above or below unity ($.90 < K_s < 1.05$); c is the velocity of light in air or vacuum; ϵ is the dielectric constant of the solid dielectric material of the bead relative to that of air or vacuum; d' is the outer diameter of the inner conductor, and D' is the inner diameter of the outer conductor in the dielectric filled line portion. It is necessary to select D' sufficiently small in value. Moreover, it is preferred to select the ratio D'/d' so that

$$D'/d' = (D/d)\sqrt{\epsilon} \tag{2}$$

The Relation 1 when an equality and 2 taken together completely determine values for D' and d'. It will be understood from Relation 1 that when d' and D' are determined as described, it may be desirable to depart therefrom slightly to compensate for the step capacitances introduced by the undercut. See for example, Proceedings of the IRE, January 1949, pages 94 to 97, "A coaxial-line support for 0 to 4,000 mc." by R. W. Corner. However, the Relation 1 still applies. Even with the factor K_s set at unity, Equation 1 is a practical equation accurate in all practical cases within about 10%. If greater accuracy is desired, the factor K_s may be obtained from S. A. Schelkunoff, Electromagnetic Waves, page 327, see Fig. 8.5; the factor K_s here is β_c in Schelkunoff.

For example, for a proposed RMA standard 50 ohm line of 6⅛" outside diameter as mentioned hereinbefore, having the teflon beads, if $D'=4.10''$ and $d'=1.23''$, the characteristic impedance is substantially equal to that of the air filled portion of the line. The cut-off frequency of the next dominant mode is 1000 MCS in the dielectric filled portion (portion of the bead). Thus the useful frequency range of the line is extended from the range of zero to about 686 MCS to the range of zero to about 895 MCS. The cut-off frequency of the air filled portion of this line is 686 MCS.

The invention may be used in conjunction with various known reflection reducing means. For example, Fig. 2 illustrated how inductive slots **22** may be employed in conjunction with the embodiment of Fig. 1. Except for the addition of the slots **22**, the embodiment of Fig. 2 is the same as that of Fig. 1. For convenience only one bead is shown. As is known, the slots **22** may be employed as a localized inductance to tune out the localized capacitance from the faces of the undercut line conductors.

Fig. 3 illustrates another embodiment of the invention which is electrically the equivalent of Fig. 1, but the mechanical construction of which is somewhat different. A metallic ring **28** is held in position by a helical metallic spring **32** which also assures contact of the ring **28** with the outer conductor **14**. If the ring is very wide, two helical springs (not shown) may be employed each near the edge of ring **28**. A dielectric bead **26** is inserted in alignment with the ring **28** and fits in an undercut portion **24** of inner conductor **12**. The irregularity **28***a* on the inner periphery of the ring **28** receives and interfits with the irregularity **26***a* of bead **26** to improve the mechanical rigidity of the parts when assembled, as is also true of the irregularity **26***b* on the inner periphery of bead **26** and the interfitting irregularity **24***a* on the under-cut inner conductor portion **24**.

The arrangement of Fig. 3 is more practical than that of Fig. 1 because difficulties of aligning and maintaining

alignment of the parts of Fig. 1 is avoided or at least simplified in Fig. 3. At the higher frequencies, currents flow only on the conductor surfaces, and the current path on the inside of the outer conductor **14** and ring **28** is almost identical with that on the inside of outer conductor **14** and the undercut portion **20**. This may be true even though there may be a slight space between the ring **28** and the outer conductor **14**. This space is so small that the high frequency energy cannot be propagated therethrough. The helix or spring **32** also assists in securing contact between the ring **28** and outer conductor **14**. Other means (not shown) are known to the art for securing an effective contact at the ring edges adjacent to the outer conductor.

Even though the dielectric bead is not uniform in its dimensions transverse to the transmission line axis, and even though the ring may be slightly spaced from the outer conductor, it has been found that the excitation of the undesired next to the dominant mode in the dielectric bead portion is substantially eliminated and at the same time a substantial match is achieved between the dielectric and air filled portions of the line by following the principles of the invention as explained above.

Thus the invention discloses means for increasing the useful frequency range of bead supported coaxial lines. The invention teaches undercutting the outer conductor of a beaded coaxial transmission line to a degree to make the next to the dominant cut-off frequency in the dielectric filled portion at least as great as that of the air filled portion, and preferably also undercutting the inner conductor of the dielectric bead portion. Preferably, the inner and outer conductors of the dielectric filled portion are undercut to equalize both the cut-off frequency of the first higher order (next to the dominant) mode and the characteristic impedance with the cut-off frequency of the first higher order mode and the characteristic impedance of the air filled portion of the lines.

What is claimed is:

1. A coaxial line comprising inner and outer coaxial conductors, and having a portion gas-filled between said conductors and a portion solid dielectric filled between said conductors, the dimensions of said line satisfying the following relation:

$$\frac{2K_s c}{\pi D'[1+(d'/D')]\sqrt{\epsilon}} \geq f_c$$

where f_c is the cut-off frequency of the next dominant mode in the said gas filled portion; K_s is a dimensionless correction factor $0.90 < K_s < 1.05$; D' is the inner diameter of the outer conductor and d' is the outer diameter of the inner conductor of the said solid dielectric filled portion; c is the velocity of light in a vacuum; and ϵ is the dielectric constant of the solid dielectric of the said solid dielectric filled portion relative to the gas of said gas filled portions; and the dimensions of the said coaxial line also satisfying the following equality:

$$D'/d' = (D/d)\sqrt{\epsilon}$$

where D is the inner diameter of the outer conductor and d is the outer diameter of the inner conductor of the gas filled coaxial line portion.

2. A coaxial line comprising inner and outer coaxial conductors, and having solid dielectric beads coaxially supporting said inner conductor with respect to said outer conductor, the portion of said line between beads being gas filled, the said outer conductor being undercut at said beads sufficiently to satisfy the following relationship:

$$\frac{2K_s c}{\pi D'[1+(d'/D')]\sqrt{\epsilon}} \geq f_c$$

where f_c is the cut-off frequency of the next dominant mode in the said gas filled portion, K_s is a correction factor greater than about 0.9 and less than about 1.05, D' is the inner diameter of the outer conductor, d' is the outer diameter of the inner conductor of the beaded por-

tion of the line, c is the velocity of light in a vacuum, and ϵ is the dielectric constant of the dielectric of said beads relative to the gas of the gas filled portion, the said coaxial line also satisfying the following equation:

$$D'/d' = (D/d)\sqrt{\epsilon}$$

where D is the inner diameter of the outer conductor and d is the outer diameter of the inner conductor of the said gas filled portion.

3. A coaxial transmission line including an inner conductor, an outer conductor, a dielectric medium of given dielectric constant located within said outer conductor and surrounding said inner conductor along at least one portion of the length of said line, a dielectric supporting member having a dielectric constant different from said given dielectric constant located within said outer conductor and surrounding said inner conductor along at least another portion of the length of said line adjacent said one portion for maintaining said two conductors in spaced relation, the inner diameter of said outer conductor and the diameter of said inner conductor being changed sufficient amounts along the length of said other portion to maintain the characteristic impedances of said two portions of line substantially the same, and to adjust the cutoff frequency of the next-to-dominant mode of wave transmission in said other portion of said line to a value at least as great as that of said one portion of said line.

4. A coaxial transmission line as set forth in claim 3, said dielectric medium comprising a gas.

5. A coaxial transmission line including an inner conductor, an outer conductor, a dielectric medium of given dielectric constant located within said outer conductor and surrounding said inner conductor along at least one portion of the length of said line, dielectric supporting means having a dielectric constant greater than said given dielectric constant located within said outer conductor and surrounding said inner conductor along at least another portion of the length of said line adjacent said one portion for maintaining said two conductors in spaced relation, the inner diameter of said outer conductor and the diameter of said inner conductor being reduced sufficient amounts along the length of said other portion to maintain the characteristic impedances of both of said portions substantially the same, and to increase the cutoff frequency of the next-to-dominant mode of wave transmission in said other portion of said line to a value at least as great as that of said one portion of said line.

6. A coaxial transmission line as set forth in claim 5, wherein said dielectric medium is air.

7. A coaxial transmission line comprising, in combination, a conductive tube; a conductor extending concentrically within said tube; a plurality of cylindrical insulators arranged at spaced intervals within said tube for supporting said central conductor, the inner diameter of said central conductor being reduced and the diameter of said metal tube being reduced at each of said insulators to an extent which will make the characteristic impedance of the sections of line in which said insulators are the dielectric substantially equal to the characteristic impedance of the sections of line between said insulators, and which will increase the cutoff frequency of the next-to-dominant mode of wave transmission in the sections of line in which said insulators are the dielectric to a value substantially equal to the cutoff frequency of the next-to-dominant mode of wave transmission in the sections of line between said insulators.

8. The coaxial line claimed in claim 5, said line further comprising longitudinal inductive slots in said inner conductor adjacent said reduced diameter portion to compensate for the local capacity effect introduced at the junction of the two line portions.

9. The coaxial line claimed in claim 5, said outer conductor comprising a tubular metallic member, the reduced inner diameter portion of said outer conductor comprising a tubular metallic ring, and a helical spring seated circumferentially around the outer periphery of each said ring and in contact with the said outer conductor member.

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