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FLEXIBLE TRANSMISSION LINE

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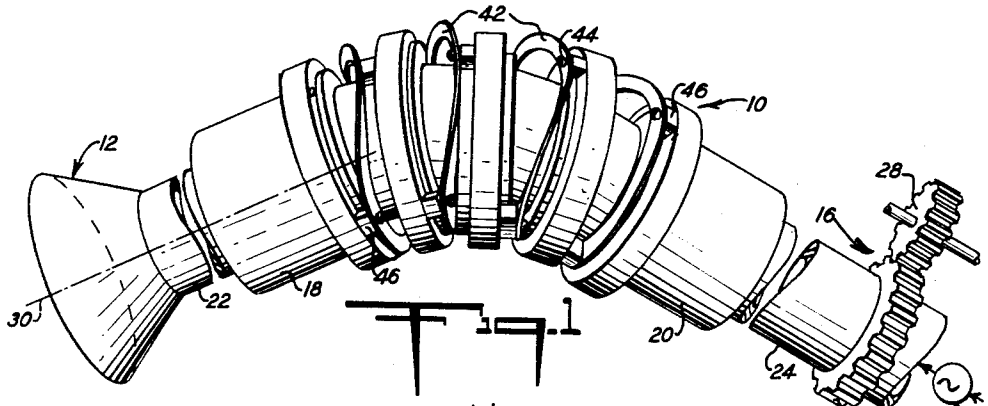


Fig. 1

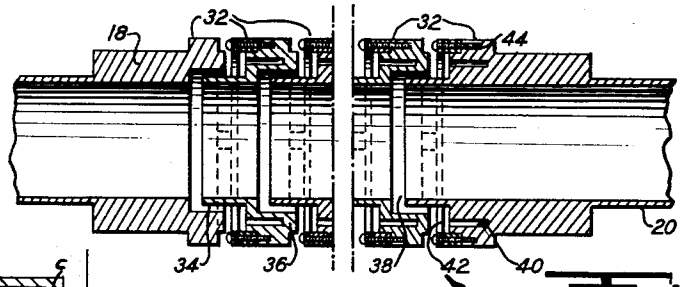


Fig. 2

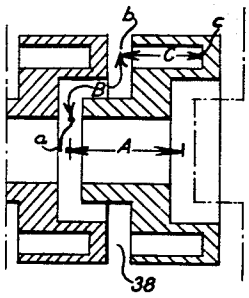


Fig. 3

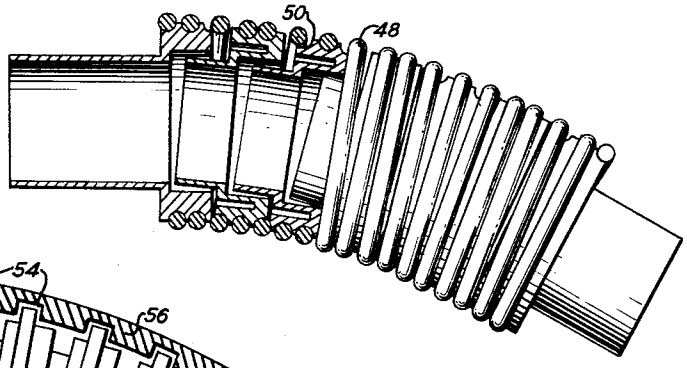


Fig. 4

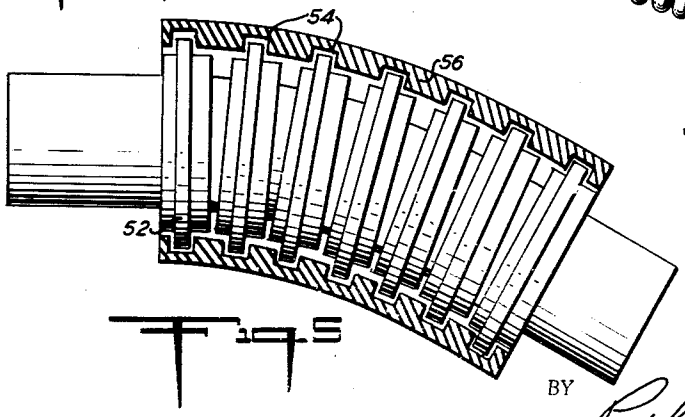


Fig. 5

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FLEXIBLE TRANSMISSION LINE

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12 Claims. (Cl. 333—95)

This invention relates to transmission lines and more particularly to a flexible transmission line of the wave guide type.

It has been known for many years that high frequency electromagnetic energy may be propagated along a hollow tube or pipe. In general the cross section of such wave guides is either round or rectangular, but other geometrical configurations have been employed on occasion. Wave guides are frequently utilized to feed electromagnetic energy to an antenna. In many instances it is desirable to rotate the antenna about an axis so that a prescribed volume of space may be scanned by the beam of electromagnetic energy radiated. It is also frequently necessary to orient the axis of the antenna in one of a plurality of directions before or during the scanning process.

In such applications the desirability of some degree of flexibility in the wave guide connected to the antenna is self evident. In the past attempts have been made to satisfy this need through the use of rotating joints of various types. Such joints are complicated, costly, and frequently are responsible for a relatively poor standing wave ratio in the overall system. An alternative solution to the problem is a wave guide which is in itself flexible.

The present invention provides a flexible wave guide which is simple to manufacture, since it may be die cast, which reduces to a minimum the overall diameter of the transmission line, and which has superior mechanical and electrical properties. The flexible wave guides of the prior art are lacking in some, if not all, of these aspects. The flexible wave guide of the present invention, on the other hand, is capable not only of transmitting electromagnetic energy efficiently and with a very low standing wave ratio, but of transmitting mechanical rotational power to a load, such as an antenna.

Accordingly, it is a primary object of the present invention to provide a unique flexible transmission line.

Another object of the invention is to provide a flexible transmission line in which the primary components may be die cast.

A further object of the invention is to provide a transmission line having a minimum overall diameter.

An additional object of the invention is to provide a flexible transmission line capable of transmitting mechanical power.

Yet another object of the invention is to provide a flexible transmission line which may be bent at any angle up to a design maximum and continue to deliver satisfactorily rotational mechanical power and electromagnetic energy.

A still further object of the invention is to provide a flexible transmission line which minimizes energy leakage and reflection.

Still another object of the invention is to provide a vertebrate transmission line having unique means for flexibly joining the vertebrae.

These and other objects of the invention are fulfilled

generally in accordance with the principles of the invention by employing tubular sections having a portion of smaller diameter and a portion of larger diameter adjacent thereto, the sections being arranged successively with the smaller dimeter portion of each section nested with the larger diameter portion of the next section. In a preferred embodiment ring-shaped springs are employed to join flexibly the successive sections.

The foregoing and other objects of the invention will become more apparent in the following detailed description of the invention when taken in conjunction with the accompanying drawing wherein:

Figure 1 is a perspective view of a preferred embodiment of the invention illustrating its use in the transmission of electromagnetic and mechanical power to a load such as an antenna;

Figure 2 is a longitudinal sectional view of a wave guide of the type illustrated in Figure 1;

Figure 3 is a longitudinal sectional view of the section employed in the invention, with the proportions distorted so that certain dimensions may be more clearly indicated;

Figure 4 is a partly sectional view of a modification of the invention; and

Figure 5 is a partly sectional view of still another modification of the invention.

Referring now to Figure 1, the flexible wave guide of the present invention, generally designated by reference numeral **10** is illustrated as connected to an antenna generally designated by reference numeral **12** for the transmission thereto of electromagnetic energy from a suitable source generally designated by reference numeral **14** and of mechanical rotational power from a suitable source generally designated by reference number **16**. No change in electrical characteristics as a function of rotation will occur if the wave guide is circularly symmetric. For this reason a circular wave guide has been illustrated and is preferred. The flexible wave guide may comprise a pair of coupling sections **18, 20**, which may be connected by suitable conventional flange coupling members (not shown) to sections of rigid wave guide **22, 24**. Section **22** is connected to antenna **12**, which, although illustrated as a circular horn, may assume any of the conventional antenna forms. Section **24** is connected to the source of electromagnetic energy **14**, which for the purposes of the present invention has merely been illustrated as a conventional high frequency generator. It will be appreciated that any of the conventional sources of electromagnetic energy may be coupled to rigid section **24** by any of the conventional means. Any mode of wave energy that can be supported in a rigid circular wave guide may be employed, for example the TE_{11} mode. It will also be appreciated that the invention is as applicable to the reception of electromagnetic energy as it is to the transmission thereof.

Mechanical rotational power may be applied to the transmission line in any conventional manner, and for the purposes of the description of the invention, a pair of gears has been illustrated. Gear **26** may be fixed to the outer surface of rigid section **24** and may be driven by a suitable pinion gear **28** driven from a motor (not shown).

Before proceeding with the detailed description of the construction of the vertebrate wave guide, it is advantageous to describe the overall function of the apparatus illustrated. Electromagnetic energy from source **14** will be propagated along the wave guide transmission line in the direction of its longitudinal axis **30**. This axis may be curved or bent by bending or flexing the flexible wave guide **10** as will be described below. In the application illustrated, rigid wave guide section **24** and the mechanical and electromagnetic apparatus as-

sociated therewith will in general remain relatively stationary on a suitable supporting platform, while rigid wave guide section **22** and antenna **12** may be moved by apparatus well known in the communications arts so that the longitudinal axis **30** points in any one of a plurality of directions. As a simple example, the antenna could be mounted in a gimbal ring suspension which would allow the antenna to be moved about two orthogonal transverse axes. The antenna and rigid wave guide section **22** could be mounted in a suitable ballbearing race on the inner gimbal ring to allow rotation about axis **30**. It will be understood that the details of the suspension of antenna **12** are not the subject of the present invention.

As will appear hereinafter, the joining means of the vertebrae which constitute wave guide **10** allow adjacent sections to move about a pair of orthogonal transverse axes. In essence the joint is universal within prescribed limits, whereby rotational power from source **16** may be transmitted to antenna **12** without changing the direction of axis **30**. The axis of the electromagnetic beam radiated by the antenna may, of course, diverge from the longitudinal axis **30** of the wave guide. This divergence, necessary for the scanning of a prescribed volume, may be accomplished in any of the conventional manners.

Referring to Figure 2, the flexible wave guide comprises a plurality of sections **32**, which may be die cast. Each section has a smaller diameter portion **34** and a larger diameter portion **36** adjacent the smaller diameter portion. The sections are arranged consecutively with the smaller diameter portion of each section nested with the larger diameter portion of the next section. Each smaller diameter portion is, of course, spaced slightly from the larger diameter portion of the next section, as indicated at **38**, to allow for relative movement between the successive sections. As will appear more fully below, an odd number of sections is preferably employed so that an even number of inter-section spaces or breaks **38** is provided. The end sections are, of course, slightly different from the intermediate sections, which may be identical, since the end sections must also serve as coupling members.

Each inter-section space or break has associated therewith a choke groove **40**. This groove is formed in the face of one of the larger diameter portions associated with each break. Figure 3 illustrates preferred dimensions which are measured in terms of guide wavelengths within the particular elemental transmission line. Dimension A, which represents the spacing of corresponding points on successive sections, is preferably a quarter wavelength of the electromagnetic energy propagated within the wave guide constituted by the inner surface of the smaller diameter portions of successive sections. This dimension may actually be any odd number of quarter wavelengths, but from the point of view of broad band operation and physical compactness, the one quarter wavelength spacing is preferred. The use of quarter wavelength spacing between successive intersection spaces or breaks provides for the cancellation of any reflected energy propagated back toward source **14** as the result of the discontinuity presented by such breaks. Considering any pair of adjacent breaks, it will be noted that energy reflected by the break farther from source **14** arrives 180° out of phase with the energy reflected by the break nearer to source **14**, and thus cancellation occurs. For cancellation to occur, it is only necessary that the breaks be arranged in pairs with quarter wavelength spacing between the breaks of each pair, and it is thus not essential that all of the sections have the same length.

Dimension B from point *a* to point *b* is preferably one quarter guide wavelength within the elemental transmission line constituted by the complementary surfaces of the successive sections which make up spaces **38**. Dimension C from point *b* to point *c* (the bottom of the choke groove) is also preferably one quarter guide wavelength within the elemental transmission line constituted by the choke groove. The total path length from point *a* to point *c* will therefore be one half guide wavelength within the composite elemental transmission line. This short circuit at point *c* will thus be reflected at point *a* as a very low impedance, and the inner surface constituted by the successive smaller diameter portions **34** will appear substantially continuous for electromagnetic energy propagated along the wave guide. The break in the outer wave guide surface effectively at point *b* will appear at a zero current point. It will be clear to those skilled in the art that the exact path lengths mentioned above are difficult to define because of the transitions which exist in the elemental transmission lines. These elemental lines comprise both coaxial and radial sections. However, the dimensions may be designated substantially as illustrated. The quarter wavelength spacing between points *a* and *b* and between *b* and *c* is preferred for reasons indicated previously, but it will be appreciated that other spacings may be employed to achieve the low impedance desired at point *a*. The use of the curved half-wave choke folded back along the guide from point *a* to point *c* allows the smallest overall outside diameter of the wave guide.

It will be appreciated that the sections may be rotated relatively about a transverse axis within prescribed limits without upsetting to a substantial degree the impedance relationships set forth above and without substantially deteriorating the standing wave ratio. The extent of allowable movement between sections will, as is understood in the art, depend upon both electrical and mechanical design criteria.

Referring again to Figures 1 and 2, in a preferred embodiment the sections are flexibly joined by ring-shaped leaf springs interposed between the sections. Each spring is connected to the adjacent sections alternately at points along its length. Preferably the points are displaced by 90° so that each spring is connected to one of the adjacent sections at two points defining a first transverse axis and to the other of the adjacent sections at two points defining a second transverse axis. These axes are preferably orthogonal. The springs may be connected to the associated sections by a plurality of bolts **44**, which may be threaded into a corresponding plurality of bosses **46** formed integrally with the larger diameter portions **36** of the sections. The choice of spring material and the thickness of the springs will, of course, determine the relative flexibility of the wave guide. It will be noted that the springs allow substantially universal movement within prescribed limits and yet prevent relative rotation of the respective sections about the longitudinal axis **30** of the wave guide.

While in the preferred embodiment illustrated the intermediate sections are substantially identical, with each section having a first pair of oppositely disposed bosses on one face and a second pair of oppositely disposed bosses on the second face displaced 90° with respect to the first pair, it will be appreciated that other arrangements for supporting the springs may be utilized. For example, alternate sections may be formed and arranged so that they support a spring on each face at opposite points with the axes defined by the points on the respective faces parallel rather than displaced 90° as in Figure 1, and the intervening sections may be formed in the same way but fixed to the springs on either side thereof at points displaced 90° with respect to the first mentioned points.

Figure 4 illustrates a modification of the invention employing substantially the same type of sections illustrated in Figures 1 and 2 but wherein the respective sections are joined by a coil spring **48** wound about the larger diam-

eter portions of the sections in a helical groove 50 formed in the outer surface of the flexible wave guide.

In Figure 5 each of the sections is provided with an integral ring shaped protuberance 52. These protuberances cooperate with corresponding grooves 54 formed in a flexible sleeve 56, which may be made of rubber for example, encasing the sections and joining them flexibly.

In a typical case for the propagation of a wave in the TE_{11} mode having a wave length of approximately 3.2 centimeters, the internal dimensions of the smaller diameter portion of the sections may be approximately 0.940 inch, while the external dimension of such portions may be approximately 1.000 inch. The internal dimension of the larger diameter portions may be approximately 1,120 inches, while the overall outer diameter of the sections may be approximately 1.780 inches. The length along the inside of the wave guide of the larger diameter portion may be approximately .350 inch, while the length of the smaller diameter portion may be approximately .420 inch. The inner diameter of the choke groove may be approximately 1.170 inches, the outer diameter of the choke groove approximately 1.350 inches, and the depth of the choke groove approximately 0.360 inch.

The embodiments described and illustrated are intended to be exemplary of the invention rather than restrictive. It will be apparent to those skilled in the art that many modifications are possible without departing from the principles of the invention. For example, while the "stepped" sections of Figure 3 are preferred for ease of manufacture, the sections could be modified so that paths B and C might form a straight path from point *a* to point *c*. The inner surface of the larger diameter portion of the sections would then be smoothly tapered rather than stepped, and the choke dimensions would be straight. Such modifications are intended to form a part of my invention, the scope of which is defined in the following claims.

I claim:

1. A flexible line for transmission of both mechanical energy and high frequency electromagnetic energy comprising a plurality of tubular sections each of said sections having a smaller transverse dimension portion and a larger transverse dimension portion, said sections being arranged in successive order, with the smaller portion of each section nested with and spaced substantially entirely from the larger portion of the next section, each of said sections being provided with a circumferential groove, the length of the path constituted by the complementary surfaces of adjacent sections defining intersection spaces and said groove causing a low impedance to appear at the breaks between adjacent smaller portions for electromagnetic energy propagated along said line, and means serving both to join adjacent sections flexibly and to transmit torque, corresponding portions of said sections being spaced along the length of said transmission line, substantially one quarter wavelength of the electromagnetic energy propagated along said line.

2. The transmission line of claim 1, said means for joining said sections comprising a plurality of leaf springs.

3. The transmission line of claim 2, each of said leaf springs surrounding a smaller portion and being joined to the adjacent larger portions alternately at points along its length.

4. The transmission line of claim 1, said means for joining said sections comprising a coil spring wound about the larger portions of said sections.

5. The transmission line of claim 1, wherein said joining means comprises a flexible sleeve encasing said sections.

6. A flexible transmission line comprising a plurality of tubular sections arranged consecutively to form a tubular wave guide, a series of ring-shaped springs arranged with one spring interposed between each pair of adjacent sections, each spring being connected at spaced points about the circumference of the ring, alternately to the adjacent sections.

7. A flexible transmission line comprising an odd number of tubular sections, each section having a smaller diameter tubular portion and a larger diameter tubular portion connected to and aligned with the smaller portion, said sections being arranged consecutively with the smaller diameter portion of each section nested with and spaced substantially entirely from the larger diameter portion of the next section, means for joining adjacent sections flexibly, and means for causing a low impedance to appear across the space between successive smaller diameter portions for electromagnetic energy propagated along said transmission line, successive spaces being separated by substantially one quarter wavelength of said energy in said transmission line.

8. The transmission line of claim 7, the last-mentioned means comprising a circumferential choke groove in one of the sections associated with each of said spaces.

9. A transmission line construction comprising an uneven plurality of tubular sections, said sections being successive with opposing surfaces of adjacent sections spaced to form a choke path for electromagnetic energy propagated in said line, said choke path having a length predetermined to cause a low impedance to appear at the breaks in said transmission line between said sections and being at least a quarter wavelength long measured along said choke path, at least a portion of the first quarter wavelength of said choke path nearest the axis of said line being folded back along said transmission line, at least one section of each adjacent pair of sections having an effective length along its wave transmission axis equal to a quarter wavelength of the energy to be transmitted.

10. A transmission line construction comprising a plurality of tubular sections, each of said sections having a smaller transverse dimension portion and an adjacent larger transverse dimension portion, said sections being consecutive with the smaller portion of each section nested with and spaced from the larger portion of the next section corresponding portions of each section, measured along the axis of wave transmission, being space apart substantially one quarter wavelength of the energy transmitted, one of the larger portions associated with each inter-section space having a choke groove therein located outwardly of the adjacent smaller portion.

11. A system for propagating electromagnetic energy between a pair of spaced devices and for moving one of said devices with respect to the other about an axis along which said energy is to be propagated, which axis may be curved; comprising a flexible transmission line having a plurality of tubular sections, each section having a smaller diameter tubular portion and a larger diameter tubular portion connected to and aligned with the smaller portion, said sections being arranged consecutively with the smaller diameter portion nested with and spaced substantially entirely from the larger diameter portion of the next section, means for joining adjacent sections flexibly, means for causing a low impedence to appear across the space between successive smaller diameter portions for electromagnetic energy propagated along said transmission line, successive spaces being separated by substantially one quarter wavelength of the propagated energy, said sections being relatively movable about a pair of transverse axes but fixed against rotation about a longitudinal axis; means for feeding electromagnetic energy to said wave guide from one of said devices and means for causing one of said devices to rotate about said longitudinal axis, thereby to rotate in turn, said transmission line and said other device.

12. The transmission line of claim 11, said sections being circularly symmetric.

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