

May 20, 1947.

A. Z. MAMPLE

2,420,712

COAXIAL CABLE AND METHOD OF MAKING SAME

Filed Nov. 26, 1942

4 Sheets-Sheet 1

FIG. 1

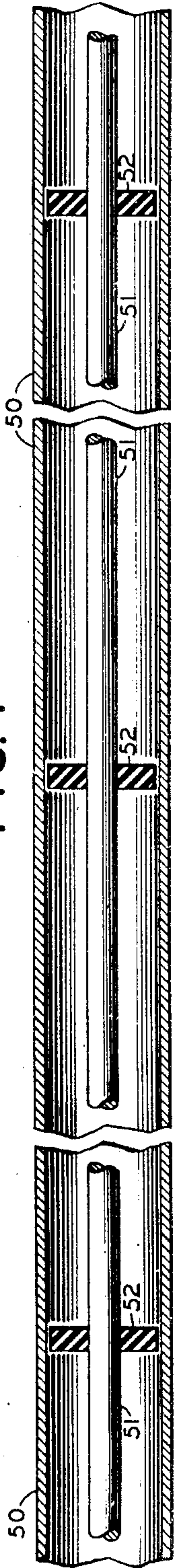


FIG. 2

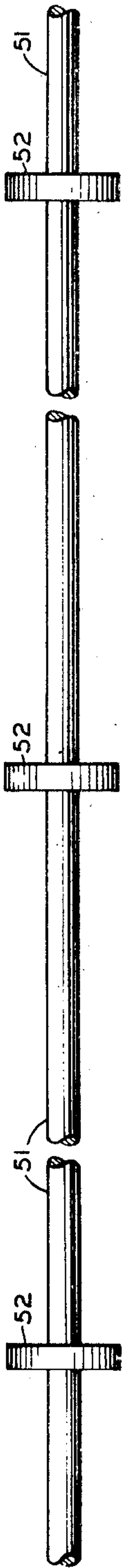


FIG. 3

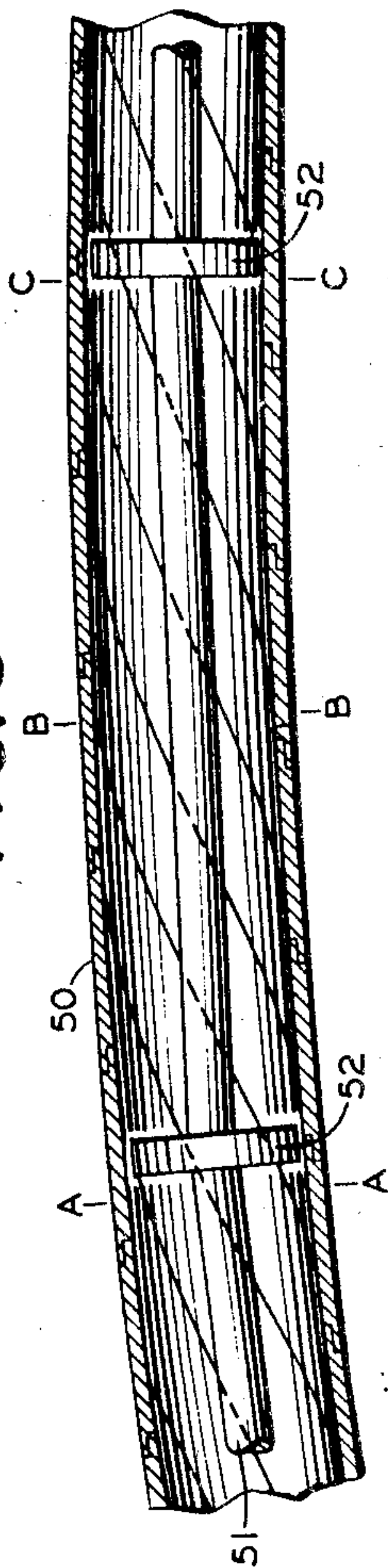
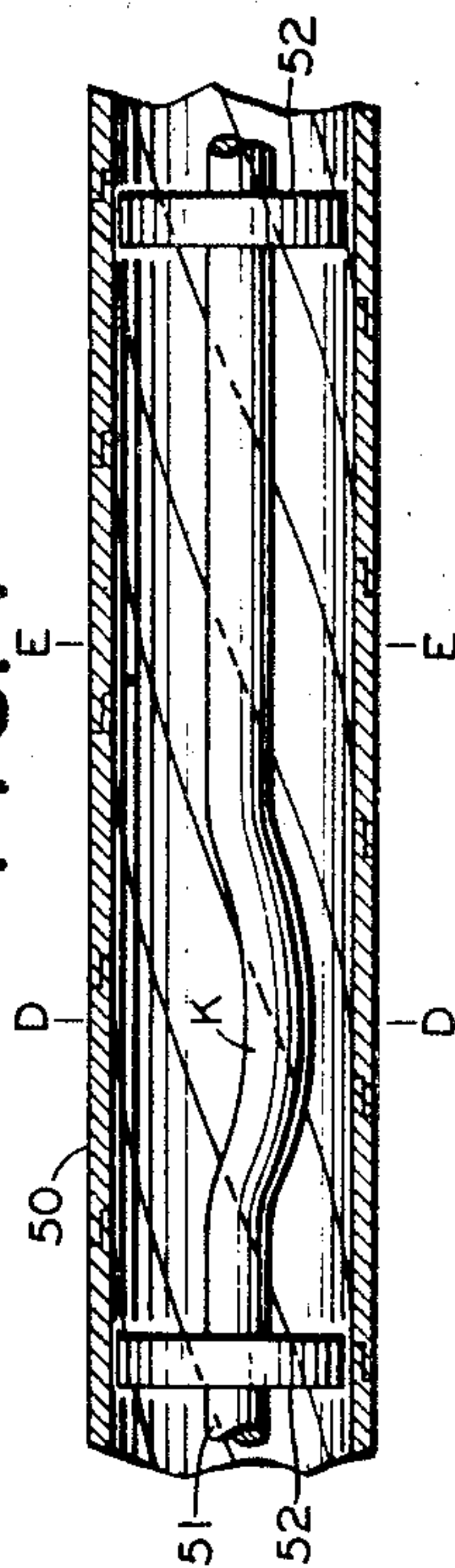


FIG. 4



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FIG. 5

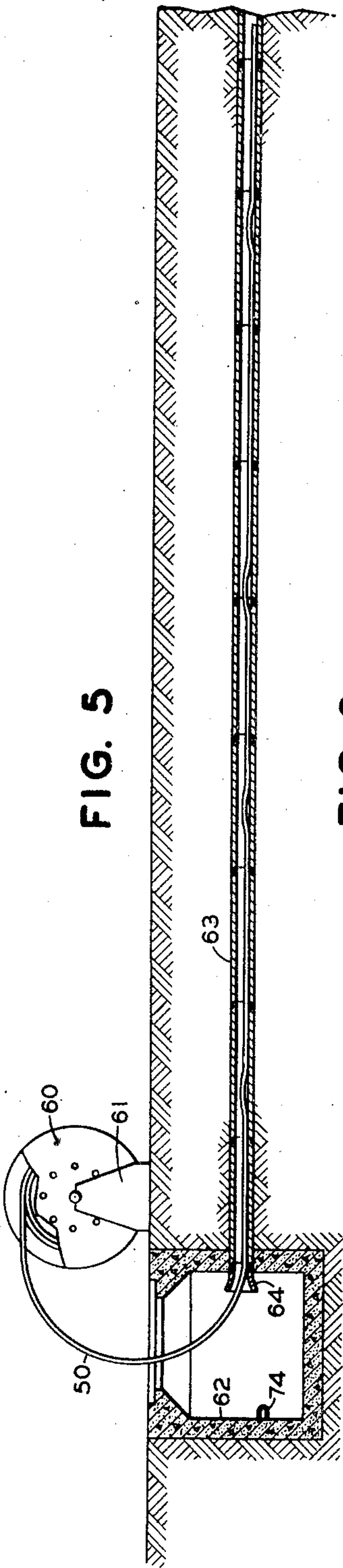


FIG. 6

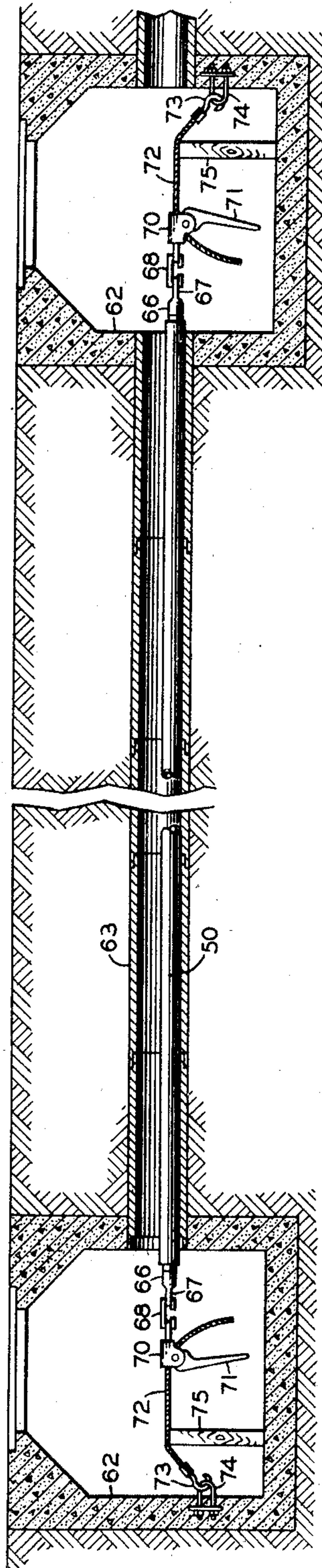
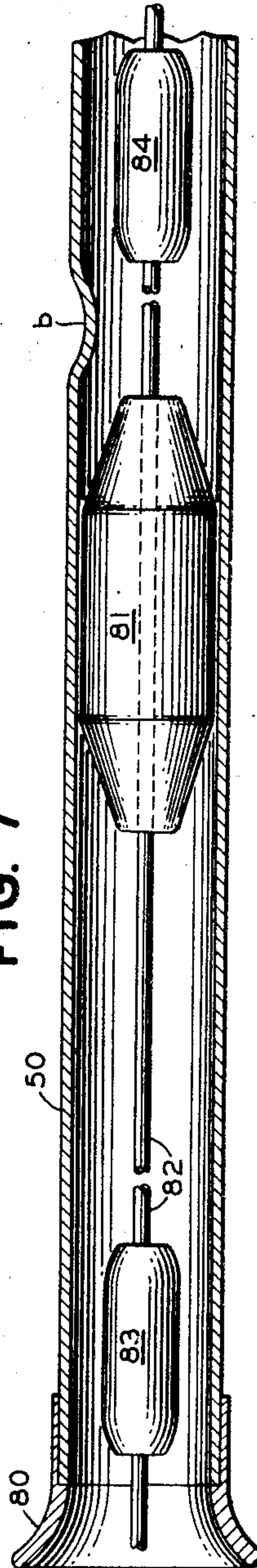


FIG. 7



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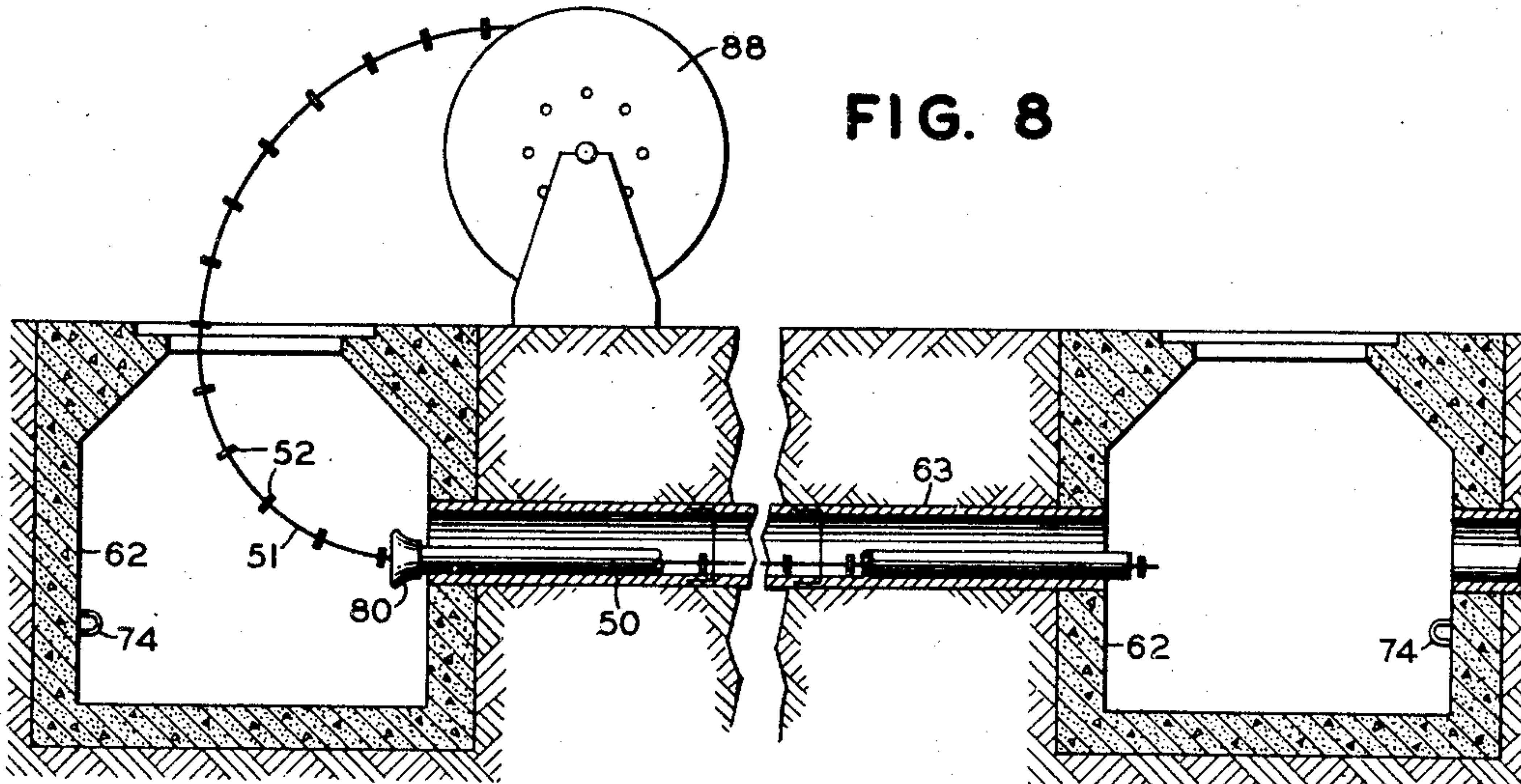


FIG. 8

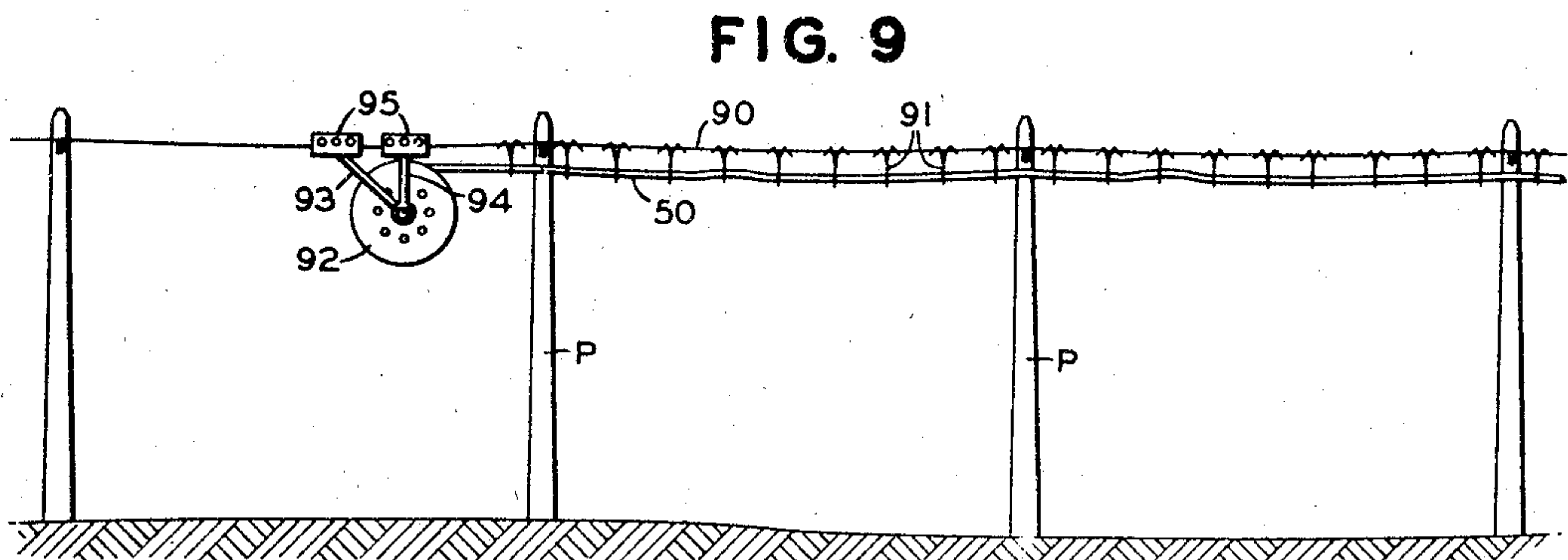


FIG. 9

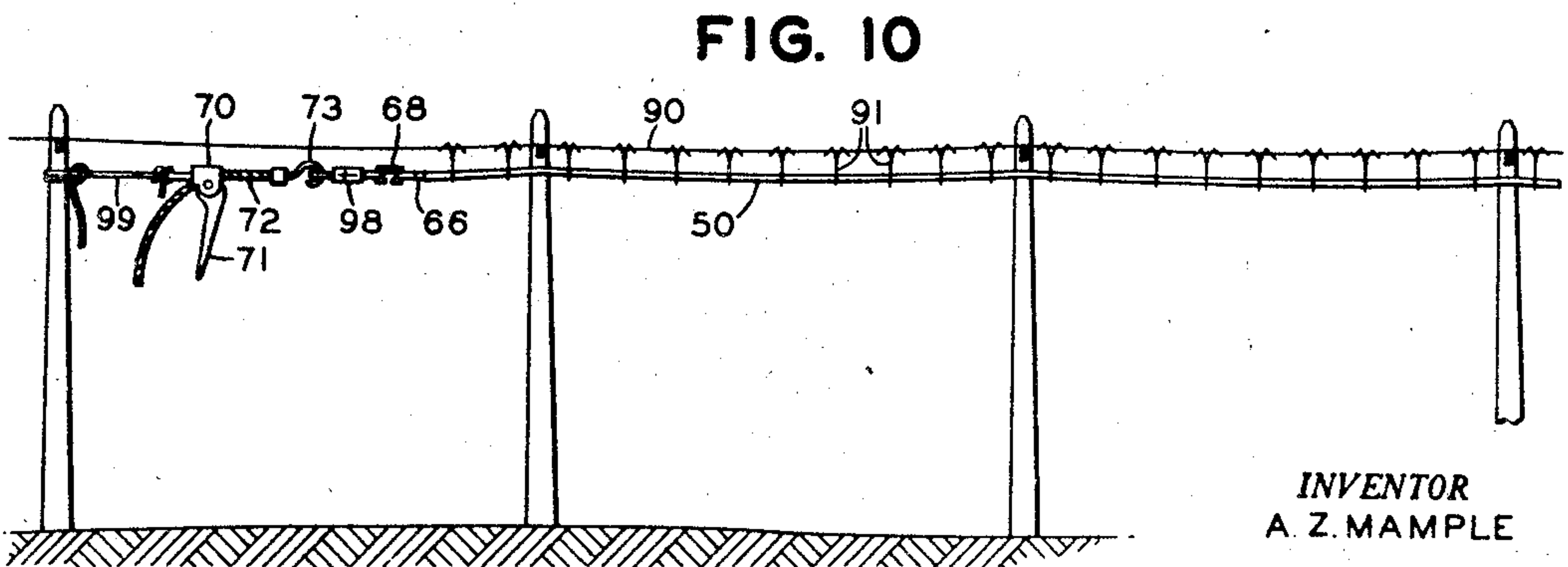


FIG. 10

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FIG. 11

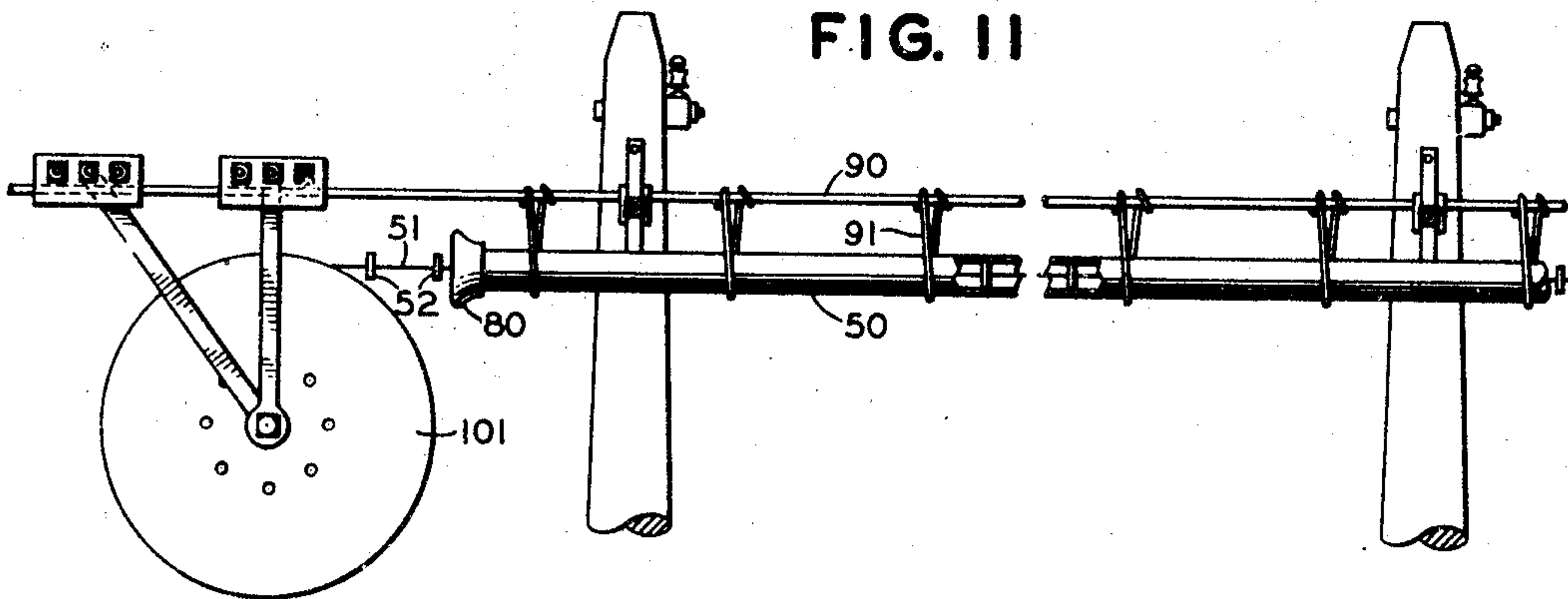


FIG. 12

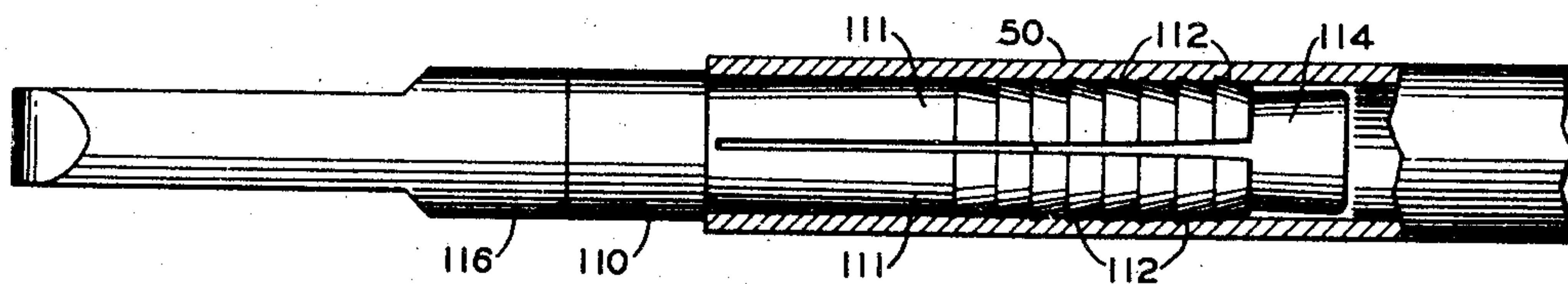


FIG. 13

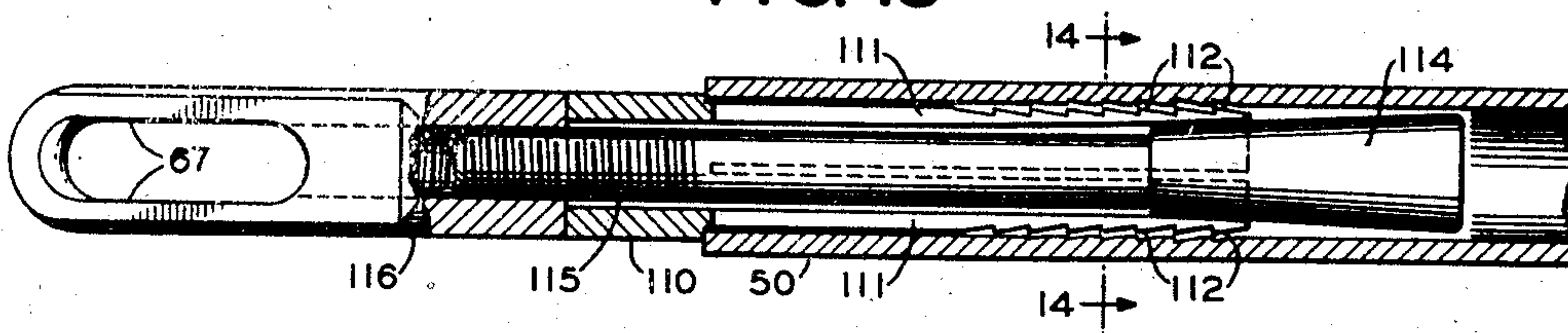


FIG. 15

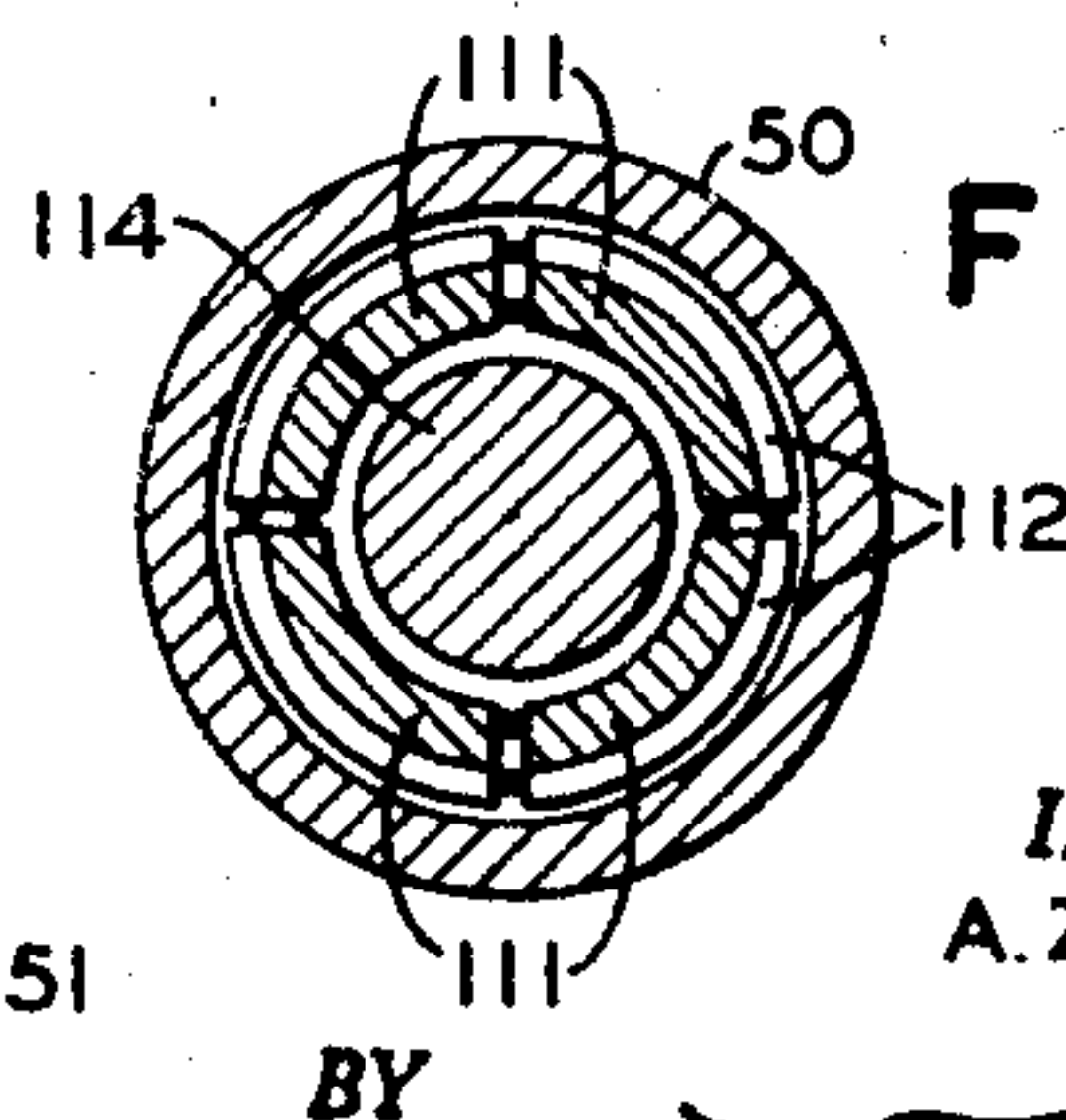
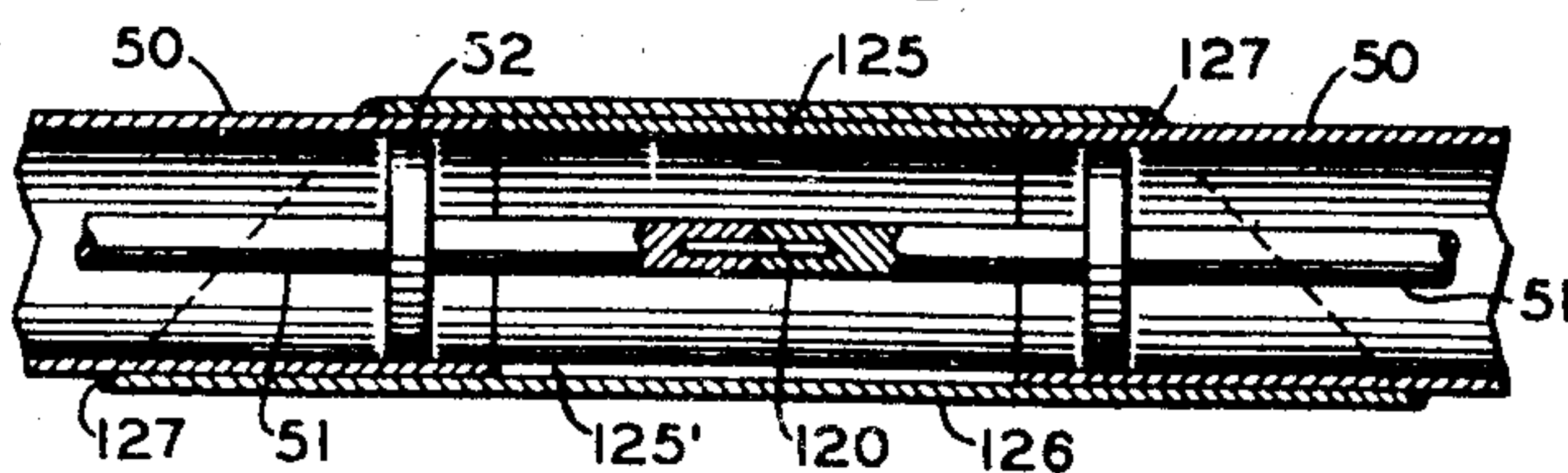


FIG. 14

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## UNITED STATES PATENT OFFICE

2,420,712

COAXIAL CABLE AND METHOD OF MAKING  
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The Western Union Telegraph Company, New  
York, N. Y., a corporation of New York

Application November 26, 1942, Serial No. 467,001

10 Claims. (Cl. 174—28)

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My invention relates to a conducting system particularly adapted for the transmission of a wide band of frequencies well above the frequencies at present employed in carrier transmission and whose upper range may be in megacycles, and more particularly to an improvement in the method of building or constructing a coaxial cable such as disclosed in my U. S. Patent No. 2,293,155, issued August 18, 1942, and to the improved cable constructed in accordance with the method disclosed herein.

The development of wide band transmission circuits has resulted in a form of circuit, generally referred to as the coaxial or concentric circuit, comprising an outer conducting tube which encloses a central conductor that is spaced from the outer tube by means of insulating discs. The high frequency transmission circuit is formed between the inner surface of the outer conductor and the outer surface of the inner conductor; the outer tubing serves both as a conductor and a shield.

In a coaxial cable system, if the two conductors be separated in so far as is possible by a dielectric consisting largely of air or other gaseous medium, the cable has a number of desirable characteristics. Its attenuation at all frequencies is quite low as compared with the corresponding attenuation of open wire lines and cable circuits such as are commonly employed for telephone and telegraph transmission. The coaxial cable may, therefore, be employed for the transmission of much wider bands of frequencies than is possible with types of transmission circuits heretofore used, and it also has the advantage of being substantially free from interference from neighboring conductor systems and in itself tends to produce but little interference into adjacent transmission circuits. In order to maintain the conductors in their relative concentric positions, it is necessary to provide the insulating washers above mentioned, but the presence of such washers increases the attenuation, and if the washers are spaced close together as has heretofore been found necessary in practice where the cylindrical conductors of the cable are of flexible construction, the amount of solid dielectric material per unit length of the cable may be increased to such an extent that the resultant increase in attenuation becomes highly undesirable.

It has heretofore generally been deemed necessary, because of the problems of installation, to provide a coaxial cable that could be rolled up on drums, hung on poles or pulled underground, and handled after the fashion of the conventional

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telephone and telegraph cables. The steps of manufacturing coaxial cables, reeling it on a cable reel, transporting it to the place of installation, unreeling, straightening out and pulling it into place, all subject the cable to various stresses such as tension, straightening, bending, compression and the like. Bending tends to make the tubular, or cylindrical, outer conductor become generally elliptical, placing the outer periphery in tension and the inner periphery in compression, while at the same time placing the inner conductor in tension, and this introduces a lack of symmetry into the coaxial system, and attempts heretofore to straighten the cable after having thus been bent introduced irregularities in the cable structure, particularly in the inner conductor, which substantially increases the attenuation of the circuit, makes the circuit more susceptible to external interference, and causes the values of the circuit to vary with movement of the cable such as in a wind. Also, any slight irregularity in the structure of the cable will make itself felt by a variation in its local characteristic impedance and cause reflection or echo effects and thus cause variation in the output impedance of the cable.

In an attempt to avoid lack of symmetry and irregularities in the structure of the cable, as stated in my aforesaid patent, the art in practice had resorted to a very close spacing of the insulating washers, and since it was found impracticable, if not impossible, to draw the outer conductor over the washers when thus closely spaced it was the practice to form the outer conductor by winding filamentary or preformed strips in a long spiral around the spacing washers, and in some cases weaving the outer conductor around the washers. Forming the outer conductor in this manner enabled manufacture of such a cable, but it has its mechanical limitations because it may readily become elliptical when bent, and also has introduced therein electrical disadvantages. Filamentary or strip construction is not satisfactory electrically because effective shielding fundamentally involves three series of loops whose planes are mutually perpendicular to each other, each of which loops could be replaced by a sheet metal to form a cube. Thus, in a shield for a conductor it involves a combination of closed loops in series whose axes run along the center of the conductor. It is evident that these loops should be uniform in resistance and of sufficiently low resistance to be an effective shield. In a filamentary spiral, spiral strip or woven outer conductor, the shielding loops must rely on the con-



tact resistance of the filamentary or spiral strips to form closed low resistance loops, and nearly all metals which would be practicable for use as an outer conductor, such as copper, form films on the surface which cause high resistance contacts. Similarly it is known that the wires forming stranded cable often vary appreciably in resistance even when adjacent wires are measured. It is evident, therefore, that filamentary or strip construction of the outer conductor in which the components parts of the loop merely touch in the spiral do not provide loops which are uniformly low in resistance, and therefore such construction does not provide the most effective shielding.

Another disadvantage of the spiral or filamentary types of coaxial cables as heretofore proposed or employed is the excessively high cost of such cables, due principally to the involved methods of manufacturing and installing the cables, and also due to the necessity for close spacing of repeaters because of an undesirably high attenuation in the cable due to close spacing of the insulating washers, irregularities in the cable structure, and the like.

An object of the invention is an improved and practicable method of constructing or fabricating a coaxial cable in which the foregoing disadvantages are obviated or substantially minimized.

Another object of the invention is an improved coaxial cable that closely approximates in practice the perfect theoretical cable electrically and mechanically when the cable is installed in place.

A further object is an improvement in a coaxial cable of the type disclosed in my aforesaid patent, whereby less care is necessary in the transportation and handling of the cable or its component parts prior to or during the installation of the cable in its permanent location, and greater latitude is permissible in regard to the place of assembly or manufacture of the cable and its component parts.

An additional object is an improved method for removing bends from the outer tubular conductor of a coaxial cable which, if permitted to remain, would introduce distortion in the coaxial circuit.

Still another object is an improved method of splicing the inner conductor of a coaxial cable to prevent any change in the diameter or configuration of the conductor at the spliced sections thereof.

Additional objects and advantages of the invention will be apparent from the following detailed description, taken in connection with the accompanying drawings, in which:

Fig. 1 is a longitudinal sectional view of a coaxial cable constructed in accordance with the present invention;

Fig. 2 is a view of the inner conductor and spacing washers prior to their insertion in the outer tubular conductors;

Fig. 3 illustrates how a lack in symmetry in a coaxial system is introduced when the cable is bent or deflected;

Fig. 4 illustrates how kinks or other irregularities are formed in the inner conductor when the cable is straightened after having been bent;

Fig. 5 illustrates one of the initial steps of making or fabricating a coaxial cable in accordance with the present invention, when employed as an underground cable;

Fig. 6 shows how any bends present in the outer tubular conductor are removed;

Fig. 7 is a view of a device employed to straighten out or remove any kinks or irregularities present in the inner surface of the outer tubular conductor;

Fig. 8 illustrates the step of pulling in the central conductor and insulating washers through the outer conductor when employed as an underground cable;

Fig. 9 illustrates the step of pulling in the outer conductor in the method of making or fabricating the cable when employed as an aerial cable;

Fig. 10 shows how bends present in the outer tubular conductor of the aerial cable are removed;

Fig. 11 shows the step of pulling the inner conductor and insulating washers into the outer conductor of the aerial cable;

Fig. 12 is a view of a preferred form of a tool inserted in the outer conductor for removing bends present in the outer conductor in the manner shown in Figs. 6 and 10, the tool being shown in gripping engagement with the conductor;

Fig. 13 shows the tool of Fig. 12 in its released position after the conductor has been straightened;

Fig. 14 is a cross-sectional view taken along the line 14-14 of Fig. 13; and

Fig. 15 shows a preferred method of splicing the outer and inner conductors of the cable.

Referring particularly to Fig. 1 of the drawings, there is shown a coaxial cable C constructed in accordance with the present invention. The outer tube 50 may be formed from a piece of seamless metal tubing, such as the flexible soft drawn copper tubing commercially manufactured and used for water lines for refrigerators, and the like. One size of such tubing which is suitable for the cable of the present invention has an outside diameter of approximately 0.625 inch and an inside diameter of approximately 0.545 inch, although various other sizes may of course be employed. While generally manufactured in short lengths of forty to fifty feet, this tubing may be obtained from various tube manufacturers in lengths of from five hundred to six hundred feet and thus provide sections sufficiently long for the practicable construction of the cable, such lengths being adapted to reach between manholes in the case of underground cables and to reach a number of spans in the case of aerial cables supported on pole lines in the usual manner. This tubing is comparatively inexpensive and does not require any special procedure in its manufacture except that it is drawn into longer lengths than usual. The inner conductor 51 of the cable may be a copper wire such, for example, as a No. 6 B. & S. gauge wire, preferably soft drawn or medium hard drawn, which has an outside diameter of approximately 0.162 inch, such size in hard drawn wire being commonly employed for telegraph circuits carried on pole lines. This wire is also comparatively inexpensive and represents a well-known commercial product obtainable from various wire manufacturers. The inner conductor is supported by and spaced from the outer conductor by means of thin insulating pieces, referred to hereinafter as washers, made of polystyrene, or a siliceous clay-like material such as Isolantite or other suitable low loss insulating material, the washers preferably being one-sixteenth of an inch thick. The spacing of the washers longi-



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tudinally of the cable may vary, depending upon the size of the coaxial cable and other factors, and in the illustrative embodiment disclosed may be spaced from four to eight inches apart.

As shown in Fig. 2, the inner conductor 51 and washers 52 are assembled, the washers being maintained in proper spaced relation longitudinally of the conductor by being cemented thereto or by very small beaded portions formed on the wire 51 adjacent to the washers, prior to the insertion of the inner conductor in the outer tube 50. If beaded portions are employed, they preferably are of the order of 0.005 inch, and thus are too small to be drawn to scale in the figure, and do not introduce irregularities in the structure of the conductor. When the inner conductor is thus formed, it may be reeled on a cable reel, preferably of large diameter, and transported to the place where the cable is to be built or fabricated. The outer tube 50 may similarly be wound on a cable reel of relatively large diameter and transported to the place where it is to be installed.

As set forth in U. S. patent to Green, No. 1,859,390, issued May 24, 1932, where the insulating washers that support the inner conductor are spaced a considerable distance apart and are themselves relatively thin, the amount of solid dielectric material present per unit of conductor length is so small as to produce substantially negative increase in attenuation over that which would be present if the entire dielectric space were gaseous. If, as stated in the patent, it is necessary for mechanical or other reasons to closely space the washers as, for example, where the inner and outer conductors are flexible, the resultant increase in attenuation may be so great as to render the system impractical as compared with former types of transmission systems.

In practice, however, because of mechanical or other reasons, it has heretofore been found necessary in filamentary or spiral construction to provide very close spacing of the washers, as close as three-quarters of an inch in a cable which has recently been installed. This undesirably close spacing of the washers was required because otherwise, when the outer conductor of a coaxial cable was subject to variations due to manufacture, and to reeling, unreeling, transporting, and the like, the conductors would develop irregularities or become asymmetrical. This will be appreciated from a consideration of Fig. 3 of the drawings, the outer tube being shown as fabricated from spirally laid metal strips. Bending of the cable due to manufacture, reeling, shipping, unreeling, straightening, and installing the same, subjects a cable to various stresses such as tension, bending, etc. Bending tends to make the tubular outer conductor become elliptical, placing the outer periphery in tension and the inner periphery in compression, while at the same time placing the inner conductor in tension. This causes the inner conductor to form chords between adjacent insulating discs, instead of maintaining its true central position with respect to the outer tubing. If the bending has been sufficient to bend the inner conductor as shown in the figure, attempts to straighten the cable will not restore the position of the inner conductor and further movement of the cable tends to change the position of the inner conductor with relation to the outer tube.

The departure from a true concentric arrangement of the conductors causes the cable to be

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subject to distortion from external disturbing fields. In Fig. 3 the line A—A indicates a place where the inner conductor 51 is properly maintained in its central position with respect to the outer tube 50 by means of the insulating piece 52. The external force produces a field in which the lines of force cutting the two concentric conductors produce differences in potential between points of the two conductors, but since the same number of lines of force cut the two conductors on the opposite sides of the central conductor the induced potentials produce current flows which are equal and opposite to each other so that a balance is obtained. Thus, where the conducting system is symmetrical with respect to the cutting lines of force, all differences in potential produced between any other two points of the two conductors will be balanced by similar differences of potential introduced in corresponding points on the other side, and no interfering effects are caused by external fields.

When, however, the central conductor 51 is displaced with respect to the outer conductor 50, as indicated by the line B—B in Fig. 3, the lines of force cutting the two conductors produce unequal electromotive forces between the points, and the unequal induced potentials exert interfering effects on the conducting system.

Also, when the outer tube 50 becomes flattened at points, as at the place indicated by the line C—C in Fig. 3, caused by bending due to manufacture, reeling, shipping, unreeling, and installing, this causes the outer conductor to become flattened on one side or elliptical, and causes the inner conductor to be brought closer to the inner surface of the outer conductor, and then the system becomes asymmetrical. The nature of these faults varies the capacity of the cable and introduces variable induced potentials into the system, thus tending to destroy one of the principal advantages of coaxial cable systems over other systems. Any change in the symmetry of the coaxial system is also reflected in another phase of an important factor of the cable, namely, attenuation. This is due to the fact that the closer the inner conductor is to the outer conductor, the greater will be the attenuation due to capacity, and the chords formed by the inner conductor shown in Fig. 3 and the tendency of the outer conductor to become flattened on one side or elliptical, bring the inner conductor closer to the inner surface of the outer conductor, and the higher the capacity the greater the attenuation of the cable.

Fig. 4 illustrates how irregularities may be introduced into the central conductor 51 when the coaxial cable is straightened after having been bent during manufacture and installation in accordance with prior methods. When the cable is bent, the inner conductor 51 was placed under tension and caused to form chords between adjacent insulating pieces, and when the outer tube is straightened, due to the fact that the inner conductor cannot readily slip through the various washers through which it passes because of the binding effect of the washers, it tends to bow or have kinks formed therein at various places along the cable, one of these kinks being indicated at k in Fig. 4. The direction which the kink may take, of course, is not determinable, but in any event it causes irregularities in the inner conductor and results in reflection, thus causing echo effects. The relatively large displacement of the inner conductor, as shown in the figure, results from the cumulative effect of the straightening



of the various adjacent chords of the conductor. The various irregularities and the disturbing effects resulting therefrom are set forth in greater detail in my aforesaid Patent 2,293,155, the disclosure of which is incorporated herein by reference.

Figs. 30, 31 and 32 of my aforesaid patent graphically indicate the increase in leakage, capacity and attenuation, respectively, caused by a decrease in washer spacing in a co-axial cable. Referring to Fig. 30 of the patent, the graph illustrates the increase in leakage expressed in  $\text{mhos} \times 10^{-6}$  per loop mile, with a reduction in washer spacing expressed in inches. It will be noted that, as the washer spacing decreases, and particularly as the spacing becomes less than approximately two inches, the leakage increases enormously, and with a washer spacing of three-quarters of an inch, which has heretofore been considered necessary in practice, particularly where the outer conductor is composed of a filamentary strip or is woven, the leakage becomes excessively high.

Fig. 31 of the aforesaid patent illustrates the increase of capacity, expressed in  $\text{farads} \times 10^{-6}$  per loop mile, and shows the excessively high increase in the capacity of the cable with the close spacing between the washers heretofore found necessary in the construction of coaxial cables. Fig. 32 thereof shows the increase in attenuation per mile of cable with close washer spacing. In each of the graphs referred to, it will be seen that, if the washer spacing can be increased so that is of the order of approximately 4 inches or more, the leakage, capacity and resulting attenuation of the cable are reduced to a value that greatly improves the electrical characteristics of the cable.

Due to the high frequencies employed in coaxial cable systems, the effect of cable irregularities on the propagation of signals is of great importance. These irregularities may result from even slight variations in the cable structure and, as hereinbefore stated, may be introduced either during manufacture or installation. Initially, a slight irregularity in the structure of either the outer or inner conductor of the cable will make this apparent by variation in its local characteristic impedance and cause reflection. There thus results a series of attenuated waves which are reflected and which return to the origin of the cable, manifesting themselves by a complex echo and by a variation of the input impedance. A second possible effect consists in a double reflection at two points of irregularity. Here a wave is produced and superimposed at the output side of the direct wave, giving rise to a prolongation of the signal, referred to as the signal tail or tailing of the signal. Such irregularities in the cable structure cause loss of energy by reflection, whence an increase in the mean attenuation results and also distortion or interruption of the signals, which effects increase with the frequency and therefore becomes increasingly important at the higher frequencies at which coaxial systems are intended to be used.

Figs. 5 to 8 illustrate a method of building or fabricating an underground coaxial cable in accordance with the invention. Referring to Fig. 5, the preformed outer tubular conductor 50 is unwound from a cable reel 60 mounted on trunnions 61 and is pulled through an underground cable duct 63 between adjacent manholes 62, a bell-mouthed guide member 64 being inserted into the duct to facilitate entry of the cable therein.

The tubular conductor 50, when thus unwound and pulled through the duct 63 to the next manhole, may in instances have curved sections or bends introduced therein due to the fact that it was not handled with sufficient care, or because it was coiled on a reel, this being liable to occur if the reel is not of sufficiently large diameter. These bends or curved sections in the tubular conductor are shown in Fig. 5, although in practice many more are present than are indicated in the figure, and to remove such bends the tubular conductor is stretched and thereby straightened by applying a tensional force thereto, as shown in Fig. 6. Referring to the latter figure, the ends of the tubular conductor projecting into adjacent manholes 62 have inserted therein a pulling tool 66. This tool expands in the end of the tube and firmly grips the same while a pulling force is applied to the tool, as hereinafter explained in detail. Each tool has a pulling eye 67 which is connected by means of a link 68 to the ratchet chain hoist or other suitable pulling device 70. When the ratchet handle 71 of the pulling device 70 is reciprocated, this causes a length of chain or wire rope 72 to be taken up by the pulling device. At one end of the chain or rope is secured a shackle 73 which is inserted in a cable pulling-in iron 74, the cable iron being firmly embedded in the concrete comprising one of the walls of the manhole 62. A wooden plank or other suitable means 75 is employed to raise the chain or rope 72 in order to insure a straight pull on the tube 50.

A very large tensional force can thus be imposed on both ends of the tube 50, at the adjacent manholes, the amount of the force required generally being dependent upon the length of the tubular conductor between the manholes. Where lengths of from 400 to 600 feet of tubular conductor are thus straightened, the tensional or pulling force required may be of the order of 1,000 pounds applied at each end, and this tensional force stretches the tubular conductor 50 slightly and to the extent necessary to pull out any bends which were introduced therein. This means that, when the inner conductor subsequently is pulled into the tube 50, the spacing between the inner conductor and the tube 50 will not vary due to curved portions or bends in the tube. The straightening or stretching operations also means that less care is required in the handling, shipping and pulling-in operation and enables smaller reels to be employed, since whatever curvature is introduced into the tubing by reason of being coiled on such a reel is effectively removed.

After the tube 50 is pulled in place and straightened, as above described, any remaining irregularities, such as the dent indicated at b in Fig. 7, are removed by pulling a three-ball hammer through the tube 50, the tube having a bell-mouthed cap 80 temporarily inserted thereon to prevent bending or kinking of the end of the tube and also to facilitate further steps in the fabrication of the cable. The three-ball hammer comprises a middle ball or mandrel 81 having conical-shaped ends, the member being slidably mounted on a rod or wire 82, the member 81 being struck, when necessary, by the two end balls or hammers 83 and 84, which are fastened securely to the pull rod or wire 82. When the three-ball hammer comes in contact with an irregularity b, the rod or wire 82 and the balls 83 and 84 thereon are drawn back and forth by the installers, producing a striking motion by



the member 81 against the irregularity *b* which is thus hammered and smoothed out to reform the tubing. Where the tube is not deformed the mandrel may be passed through quite easily, but where it is deformed the mandrel will reform it into a tube of true circular cross-section. The largest diameter of the member 81 is but a few thousandths of an inch less than the normal inside diameter of the tubing 50. After the three-ball hammer is thus worked through the tube 50 from one manhole to the next manhole, the inside of the inner diameter of the tube 50 will be uniform throughout the length thereof and all elliptical sections, buckles, dents, etc., in the tubing will have been removed. The tube 50 is now ready for the insertion of the inner conductor and spacing washers.

Fig. 8 shows how the inner conductor 51 and the spacing washers or discs 52 are pulled from a reel 88 into the outer tube 50. With a washer spacing of five inches, in a cable of the size hereinbefore stated, a pulling force of the order of 20 lbs. per hundred feet of cable is necessary to overcome the friction between the insulating discs and the outer tubular conductor, and even though lengths of from 500 to 600 feet of the inner conductor are thus pulled in, the total pulling force required does not appreciably elongate the copper wire comprising the inner conductor.

After the inner conductor has been pulled in through the tube extending between adjacent manholes, irregularities in the wire 51 are removed by employing a suitable straightening device for placing the wire under the necessary tension, such a device being shown in Fig. 6 herein, although other devices may be used for this purpose, such as the device shown in Fig. 23 of my aforesaid patent. The arrangement of Fig. 6 herein may be employed as shown in this figure, except that a wire gripping and pulling device, which may be of a type well known in the art, such as a Buffalo grip or come-along, is employed in lieu of the tube gripping device 66 shown in the figure. The amount of stretching force applied to the inner conductor to straighten it, however, is not nearly so great as that required for straightening the tube 50. Where the inner conductor is, for example, from 400 to 600 feet long, a stretching force of the order of 300 pounds will usually be found sufficient to remove any kinks or irregularities which may have been introduced into the wire. Instead of employing two stretching devices, as shown in Fig. 6, one end of the inner conductor 51 may be anchored in any suitable manner, as to the pulling-in iron 74, at one end of the manholes, and the stretching operation effected at the adjacent manhole, although in the case of long sections of cable, it will usually be found desirable to employ straightening devices at both manholes.

Inasmuch as the inner diameter of the outer tube 50 now represents a true circle throughout the length thereof, and the conductor 51 is straight and true, and the washers 52 are perfectly concentric with an outer diameter of only a few thousandths of an inch less than the inner diameter of the outer conductor 50, this causes the inner conductor to be uniaxial with respect to the outer conductor and thus result in a symmetrical coaxial cable.

As above stated, the outer conductor 50 is a perfect circular unit conductor, and it will be apparent that with no unequal tension on the inner conductor 51 with relation to the outer conductor, there are no forces tending to form

chords from washer to washer or to pull the inner conductor out of alignment with the axis of the outer conductor. The symmetrical cable thus formed will thus permit of no induced disturbing potentials, and no increases or variations in attenuation due to capacity because of unequal spacing of the inner conductor with relation to the outer conductor, and eliminates the undesirable echo effects. It will further be evident that the perfect condition of the completed coaxial cable obtained does not require extra close spacing of the insulating washers since the method by which the cable has thus been built or straightened in situ has eliminated the necessity for such close spacing. As above explained, this results in further reduction of attenuation due to the lower capacity and leakage conductance of the washers.

It will further be noted that the outer conductor consists of a series of completely closed loops uniformly low in resistance whose axes coincide throughout with the axis of the cable. Therefore the cable is better shielded in that it provides a uniformly low resistance return conductor. These improvements not only provide a cable with lower and non-variable attenuation characteristics, but also result in a cable with a very low noise level. Because of the more efficient shielding it also results in a complete absence of coupling of external fields. The cable may therefore be attenuated to a lower level, thereby permitting a wider spacing of repeaters. The construction of the cable by the method herein disclosed, made as it is largely from commercially available materials, has the added advantage that the resulting cable costs only a fraction (approximately 20%) of the coaxial cables heretofore proposed or installed.

Figs. 9 to 11 illustrate the invention as applied to an aerial coaxial cable. Referring to Fig. 9, there is shown a pole line *p* carrying a cable supporting strand or messenger 90, to which are secured cable hangers 91 through which the outer tubular conductor 50 is pulled. The tube 50 may conveniently be pulled from a special lightweight reel 92 rotatably supported by members 93 and 94 on each side of the reel, the latter members being readily secured by means of clamps 95 to the supporting messenger 90. Since the cable reel 92 and copper tubing thereon are relatively light in weight, the reel and cable thereon may easily be hoisted by a line into position for mounting on the supporting messenger 90.

When a desired length of the tube, such as a length sufficient to reach several spans of pole line, has been pulled in through the cable hangers, the tube is straightened to remove bends which may have been introduced therein, generally in the manner in which the underground tube 50 of Fig. 6 was straightened. As shown in Fig. 10, the tube gripping device 66 is secured by means of the link 68 to one end of a dynamometer 98 which is employed to determine the amount of pulling tension applied to the tube 50. In this connection it is also desirable to use such a dynamometer when stretching the underground conductor 50 of Fig. 6, and also the inner conductor 51. The dynamometer is secured at its other end to the shackle 73 of the chain hoist or other pulling device employed. The pulling device 70 may be anchored or secured in any suitable manner, as to an adjacent pole by means of a wire rope or chain 99, as shown in Fig. 10, or it may be secured by clamping the rope or chain to the messenger 90, or by a line passing through a pulley attached



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to the pole or to the messenger, the line being secured at an adjacent pole or other suitable object. Preferably, the pulling force is exerted on the cable at both ends of the section, generally in the manner shown in Fig. 6. The straightening operation removes the various bends in the cable which are indicated in Fig. 9, and after the operation the cable is straight and true except for the slight sag which is occasioned by reason of the sag of the supporting messenger intermediate the points of its support on the pole line.

After the tube 50 has been pulled in place and straightened as aforesaid, any remaining kinks, bends or irregularities in the inner surface of the tube may be removed by pulling a three-ball hammer through the tube in the manner hereinbefore described with reference to the underground cable.

Fig. 11 illustrates the step of pulling in the inner conductor and washer assembly. The inner conductor 51 and washers 52 may be carried on a special lightweight reel 101 supported from the cable messenger 30 in the manner shown. After the inner conductor and insulating washers are pulled into the tube 50, the end of which is protected by the bell-mouth guide 30, the conductor 51 is stretched in the manner hereinbefore described in connection with the underground cable, to remove any kinks, bends or irregularities in the conductor. The result is that the aerial coaxial cable is truly symmetrical and exhibits the same desirable characteristics as the underground cable referred to above. By reason of the fact that bends and curves in the outer tube 50 may be removed in the manner disclosed hereinbefore, such tubing may be coiled on smaller reels than was heretofore possible, and even if the tubing has become bent in certain places to an extent tending to produce an elliptical configuration, the straightening and hammering operations restore the tubing at such places to a circular configuration. Also, for certain purposes and in certain types of circuits in which some departure from symmetry of the conductors of the cable may be permissible, the cable may be assembled in a cable manufacturing plant, and then reeled and transported to the place where it is to be installed. After a length of the cable has been pulled in place and cut off, the ends of the inner conductor, if desired, may be removed a slight distance sufficient to permit the insertion of the stretching tool 66 into the ends of the tubing, and with a suitable amount of stretching force exerted on the outer tubular conductor, the cable may be caused to have suitable characteristics for the purpose intended. This procedure may also be followed with the inner conductor in the manner hereinbefore referred to, and in such case a short piece of the outer tube may be cut away to enable wire gripping devices to engage the inner conductor for the purpose of straightening the same.

Figs. 12 to 14 illustrate a preferred form of a tube engaging and straightening tool which may be employed for straightening the outer conductor. The tool comprises a hollow circular steel body portion 110 which has an expanding casing formed by splitting the body portion to provide expanding leaves 111, this expanding casing being inserted a short distance into the end of the tubing as shown in Figs. 12 and 13. On the expanding casing are formed a series of circular tapered teeth or gripping portions 112. Within the expanding casing is a tapered ex-

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panding nut or plug 114, the nut having integral therewith a threaded rod portion 115 which is received within the threaded portion of a rotatable shank 116, the shank having a pulling eye 67 formed therein as shown in Fig. 13. When the shank 116 is rotated in the proper direction, this causes the threaded rod 115 to be advanced through the threaded portion of the shank 116, from right to left as viewed in the figure, thereby pulling the expanding nut 114 into the expanding casing 111 and forcing the teeth 112 outwardly to engage and grip the inner surface of the tube 50, as shown in Fig. 12. While the teeth 112 bite into the inner surface of the tube 50 to a slight extent, this ordinarily will not affect the characteristics of the cable, although if desired the end portion of the tube 50 into which the expanding tube is inserted may be cut off after the straightening operation is completed. It is to be understood that other suitable gripping devices may be employed in lieu of the device shown in Figs. 12 to 14, although this device is preferred since it does not deform the structure of the tube 50 when a straightening stress is applied thereto.

The various sections of the coaxial cable, whether aerial or underground, may be spliced together in any suitable manner. A preferred method of splicing the ends of the conductors 51 of the adjacent sections together is shown in Fig. 15, these ends being both mechanically and electrically joined by means of a metal connector pin 120 which is inserted with a tight fit in holes drilled in the ends of the abutting sections of the conductors 51. A small amount of solder is then applied to the splice where the adjoining conductors abut, and the splice further heated, and by capillary attraction the solder is caused to flow between the abutting ends and also between the adjoining surfaces of the pin 120 and the holes in the conductors 51 which receive the pin. This forms a sweated joint which is both electrically and mechanically strong, and the joint causes no increase or change in the diameter or configuration of the inner conductor 51 at the point where the adjacent sections of such conductor are spliced together. After the inner conductors 51 have thus been joined together, a copper sleeve 125, which is longitudinally split at 125', is opened up sufficiently to slip the sleeve in place so that it abuts the two ends of the outer tubes 50, after which a connector sleeve 126 is soldered at 127 to the tubes 50, and thus the inner surface of the outer tube is smooth. As shown by dotted lines in the figure, the ends of the sleeve 125 are cut at an angle to cause the solder to flow in between the sleeve and adjoining tubes 50, generally by capillary attraction, thereby to provide a sweated moisture-proof and gas-proof joint.

The sweated joint disclosed in Fig. 15 provides a connection between the adjacent ends of the inner conductor 51 which is ideal from an electrical standpoint, but if greater mechanical strength is required as, for instance, to enable spliced sections of the conductor to be pulled in the abutting ends of the conductors may be brazed, a suitable brazing material for producing butt joints being employed. Such a brazing material may comprise one of several known brazing materials in the market, preferably those having a melting point as of the order of 1100° F. The brazed joint will cause the spliced section of the conductor to have a strength of approximately 100% of the conductor itself, so that the



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spliced portions are as strong as the unspliced portions of the conductor. Moreover, the brazed joint is ideal from an electrical standpoint, since it introduces no appreciable increase in resistance by reason of the spliced portions. The method of thus brazing the abutting ends of the conductors may be the same as that employed in brazing the abutting ends of other metallic bodies, and suitable brazing methods are well-known in the art. When making a brazed butt joint, the pin 120 may either be used or omitted, as desired; when used, its principal advantage is that it enables the abutting ends of the conductor 51 to be held in proper alignment during the brazing operation, although other devices may be employed for this purpose. The diameter and configuration of the conductor 51 will remain unchanged at the brazed portions, and thus there is no change either in the impedance of the conductor 51 or in the capacity effect between the outer surface of the conductor 51 and the inner surface of the tube 50, and there is no extension or protuberance of the conductor 51 which would tend to cause echo effects or other disturbances in the coaxial circuit.

An important advantage in the foregoing construction is that the outer, preformed copper tubing 50 is moisture-proof and gas-proof and therefore it is not necessary to provide an outer sheath of lead or the like to prevent the entrance of moisture or loss of gas, as is required when strip, filamentary or woven conductors are employed for a concentric cable. The copper tubing, with the inner conductor and insulating washers therein, may be carried in underground cable ducts or in aerial cable hangers of standard construction, generally in the manner of the conventional lead cables employed for telegraph and telephone work. Two or more coaxial cables in accordance with the present invention may be laid side by side in ducts or in cable hangers or other supports without substantial interference between their respective circuits. Also, if desired, where signal or repeater power feed circuits are employed, an outer sheath of lead or other suitable material may be used for enclosing one or more coaxial cables and also communication or power feed conductors, the outer sheath affording the necessary protection for the additional conductors.

The present invention enables the use of an outer conductor of seamless flexible tubing of copper or other suitable metal, and thus no seams are required in the outer tube. Also, by reason of the fact that bends or curves are removed from the outer conductor and that all irregularities are removed from the inner surface of the outer conductor and any kinks or bends removed from the inner conductor, the washer spacing may be greatly increased. The increase in washer spacing facilitates the fabrication of the present cable, since there is less friction between the washers and the outer tube when the inner conductor and washers are pulled in place, and appreciably decreases the undesirable capacity, leakage and attenuation characteristics of the cable, so that the performance of the cable very closely approximates that of a theoretical coaxial system, and makes the cable adaptable for very high frequencies such as of the order of 4 or 5 megacycles and higher. While the washer spacing may be of the order of from 4 to 8 inches, it will be understood that if a smaller washer spacing is desirable, for example, a 2 or 3 inch spacing, this can readily be attained, and conversely

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the washer spacing may be greater than 8 inches, depending upon the size of the cable, the nature of the inner conductor, and other factors. The outer tube preferably is composed of soft drawn copper and the inner conductor preferably is composed of soft drawn or medium hard drawn copper wire, the resistance of which is less than that of hard drawn copper, although it will be appreciated that hard drawn copper wire may be employed for the inner conductor and that materials other than soft drawn copper may be employed for the flexible outer tubing.

There are other important advantages incident to stretching the outer conducting tubing. One is that the tubing may originally comprise soft drawn copper which is easy to handle due to its flexibility and is easy to stretch and straighten due to its ductility, and after the tubing is installed in its permanent location the stretching operation hereinbefore referred to changes the soft drawn copper to a medium hard-drawn copper so that, after the stretching and straightening operation, the tubing has a further desirable characteristic in that it has now been changed to a medium hard-drawn copper tube and this gives greater strength and rigidity to the tube and materially prevents collapse of the tube at any portion thereof due to mechanical forces which the cable may encounter in service.

Moreover, the step of stretching the outer tubing has an important advantage in that it enables the inner conductor and washer assembly to be pulled into the tubing in longer sections. If bends were left in the tubing, the frictional resistance of the inner conductor and washer assembly as it is pulled in increases enormously with the length of the conductor because of the excessive friction between the peripheral edges of the insulator pieces and the bent portions of the outer tube, plus the unit linear frictional resistance. The pulling force required in certain instances would exceed the ultimate tensile strength of the inner conductor or at least stretch the inner conductor unduly and thus undesirably reduce its diameter. Reduction of the diameter of the inner conductor in this manner also tends to cause stripping of the washers as the conductor was pulled in. However, when the outer tubular conductor is stretched and straightened in the manner disclosed, the pulling-in force required is reduced to an amount only necessary to overcome the unit linear frictional resistance. Thus, the pulling force required is approximately proportional to the length of the conductor. The force required for pulling in long lengths of the inner conductor never reaches the point where it is excessive or where it tends to cause the disadvantages mentioned above which would result from the necessity of employing a much greater pulling force.

While, as hereinbefore, set forth, the bends, kinks and irregularities preferably are removed from the outer and inner conductors of the coaxial cable when it is in its permanent location, or in some other location such that it may be pulled into place without introducing substantial bends and irregularities therein, it is possible that for certain classes of service the cable may be manufactured at a plant and lengths of the cable reeled, transported and installed with all of its component parts intact. By reason of the fact that, when the outer tubing was straightened and stretched at the manufacturing plant, it thus became medium hard drawn, and



if relatively large reels are employed for transporting the lengths of cable, the likelihood or danger of collapse of the cable is greatly lessened, since the medium hard drawn copper does not tend to collapse, as is the case with soft drawn copper tubing.

It will be understood that, even some slight bends or other slight irregularities are introduced into the cable structure, they may be of a character which would not introduce distortion in excess of a predetermined permissible amount in the coaxial circuit, the permissible amount depending upon the nature of the service, the signaling frequencies employed, the proximity of disturbing circuits, and other factors. For example, if it is desired to use a cable with frequencies of less than approximately one million cycles, the echo effects and other disturbances due to irregularities in the cable structure are not so pronounced as they are in the higher frequencies of the order of several megacycles and above. In this connection, the fact that both the inner and outer conductors are spliced in such a manner as to maintain the diameters of the spliced portions the same as the remaining unspliced portions of the conductors means that there are no echo effects or disturbances introduced by reason of changes in diameter due to splices throughout the entire range of frequencies for which the cable is adapted, including the lower frequencies as well as the very high frequencies, so that any disturbances due to splicing is eliminated as a factor, and this enables a certain amount of other irregularities to be tolerated in the lower frequency range.

While the tool illustrated in Figs. 12 to 14 is there shown as employed for stretching and straightening the conductor, the character of this tool is such that it is also well adapted for pulling in the outer tubing either through bridle rings in the case of aerial cables or through ducts in the case of underground cables, and this pulling-in operation is, therefore, effected without distorting the copper tubing. The tool also has the advantage in that the extent to which the expansible portions 111 and 112 grip the tubing is proportional to the amount of pulling force required; in other words, in pulling in the tube it is only necessary that the shank 116 be rotated so as to cause the portions 112 to firmly grip the inner surface of the copper tubing, and any additional force required is only that due to the force imposed on the tool by the pulling-in operation, so that the force with which the tool engages the tubing at no time is greater than that necessary for pulling it in, or for stretching, and never reaches an excessive amount. The gripping action of the tool is, therefore, always automatically adjusted to the pulling force required.

The cable may be filled with a suitable inert gas, such as nitrogen, which is maintained under pressure higher than atmospheric pressure in order to prevent the entrance of moisture because of an injury to or fault in the outer tube 50. The gas also forms an ideal dielectric between the conductors of the cable and further provides means for making tests in the outer conductor to indicate the presence of an injury or fault. The gas may be introduced into the cable by means of valve connections generally in the manner disclosed in Patent No. 1,998,766, issued April 23, 1935.

In order to sectionalize or terminate the cables, cable dams may be employed such, for example, as disclosed in Patents Nos. 1,769,524 and 2,293,-

155. The provision of cable dams enables the cable readily to be tested for defects in the sheath and splices. Various arrangements and signal systems may be employed for locating defects in the gas-filled cable, such systems being disclosed in Patents Nos. 2,071,698 and 2,219,262.

While, as above set forth, the bends, kinks and irregularities preferably are removed from the outer and inner conductors of the coaxial cable when it is in its permanent location, or in some other location such that it may be pulled into place without the danger of introducing bends and irregularities therein, it is possible that for certain classes of service the cable may be manufactured at a plant and lengths of the cable reeled, transported and installed with all of its component parts intact, particularly if sufficiently large reels are employed for storing and transporting the lengths of cable. In this connection, it is possible that if some slight bends or other slight irregularities are introduced into the cable structure, they may be of a character which would not introduce distortion in excess of a predetermined permissible amount in the coaxial circuit, the permissible amount depending upon the nature of the service, the signaling frequencies employed, the proximity of disturbing circuits, and other factors.

For brevity in the claims the expression "installation" is employed in a generic sense to define the cable assembly in its permanent location or in some other location such that it may be transported and installed in its permanent location without substantially affecting deleteriously the desired condition or characteristics thereof recited in the claims; similarly, the expression "in situ" is employed in a generic sense to define the permanent location of the cable or some other location such that the cable may be transported and installed in its permanent location without substantially affecting deleteriously the desired condition or characteristics thereof recited in the claims; the expression "flexible" applied to the inner and outer conductor elements of the cable means that these elements, as opposed to rigid, are sufficiently non-rigid as to be capable of being coiled or placed on reels for storage, transportation or other purposes; and the expression "long lengths" employed means lengths sufficiently long for the practicable construction of the cable, for example, lengths adapted to reach between man-holes in the case of underground cable construction or between poles in the case of aerial pole line construction.

It will be evident to those skilled in the art to which the present invention pertains, that the invention is not limited to the specific methods and structures shown and described, and that various changes and modifications therein may be made, and I therefore do not desire to be limited to the precise method and structure shown and described except in accordance with the appended claims.

What is claimed is:

1. In the method of making a high frequency coaxial cable having a flexible outer conducting tube that encloses a flexible inner central conductor spaced from the outer tube by insulating pieces through which the central conductor passes, the step which comprises applying to said outer tubular conductor a tensional force sufficient to uniformly stretch the tubular conductor to remove therefrom bends of a character which would introduce distortion in excess of a prede-



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terminated permissible amount in the coaxial circuit.

2. In the method of making a high frequency coaxial cable having a flexible outer conducting tube that encloses a flexible inner central conductor spaced from the outer tube by insulating pieces through which the central conductor passes, the step which comprises applying to an end of the outer tubular conductor a tensional force sufficient to uniformly stretch the tubular conductor to remove therefrom bends of a character which would introduce distortion in excess of a predetermined permissible amount in the coaxial circuit.

3. In the method of making a high frequency coaxial cable having a flexible outer conducting tube that encloses a flexible inner central conductor spaced from the outer tube by insulating pieces through which the central conductor passes, the steps which comprise applying to the outer conductor a tensional force sufficient to uniformly stretch said outer conductor so as to remove therefrom bends of a character which would introduce distortion in excess of a predetermined permissible amount in the coaxial circuit, and applying a tensional force to said inner conductor to uniformly stretch said inner conductor to remove bends and kinks therefrom.

4. The method of making a high frequency coaxial cable having a flexible outer conducting tube that encloses a flexible inner central conductor spaced from the outer tube by insulating pieces through which the central conductor passes, which comprises securing to the central conductor in predetermined spaced relation longitudinally of the conductor insulator pieces of slightly less diameter than the inner diameter of the outer tube, applying to the outer tube a tensional force sufficient to uniformly stretch the outer tube to remove therefrom bends of a character which would introduce a distortion in excess of a predetermined permissible amount in the coaxial circuit, drawing the central conductor and insulator pieces secured thereto through said outer tube until the inner conductor and spacing pieces are properly positioned within the outer tube, and then applying a tensional force to said inner conductor to uniformly stretch the inner conductor until bends or irregularities therein are smoothed out.

5. The method of making a high frequency coaxial cable having a flexible outer conducting tube that encloses a flexible inner central conductor spaced from the outer tube by insulating pieces through which the central conductor passes, which comprises securing to the central conductor in predetermined spaced relation longitudinally of the conductor insulator pieces of slightly less diameter than the inner diameter of the outer tube, applying to the outer tube a tensional force sufficient to uniformly stretch the tube to remove therefrom bends of a character which would introduce distortion in excess of a predetermined permissible amount in the coaxial circuit, passing a shaping device through said tubing to remove kinks and irregularities from the inner surface of said tubing, subsequently drawing the central conductor and insulator pieces secured thereto through said outer tube until the inner conductor and spacing pieces are properly positioned within the outer tube, and then applying a tensional force to said inner conductor to uniformly stretch the inner conductor until bends or irregularities therein are smoothed out.

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6. The method of making a high frequency coaxial cable having a flexible outer conducting tube that encloses a flexible inner central conductor spaced from the outer tube by insulating pieces through which the central conductor passes, which comprises securing to the central conductor in predetermined spaced relation longitudinally of the conductor insulator pieces of slightly less diameter than the inner diameter of the outer tube, installing in situ a section of the outer tube, applying to the section thus installed a tensional force sufficient to uniformly stretch the section to remove therefrom bends of a character which would introduce distortion in excess of a predetermined permissible amount in the coaxial circuit, passing a shaping device through said section of the tubing to remove kinks or irregularities from the inner surface of the tubing, drawing the central conductor and insulator pieces secured thereto through said installed section of the tubing until the inner conductor and spacing pieces are properly positioned within the outer tube, and applying a tensional force to the inner conductor to uniformly stretch the conductor thus installed to remove kinks and irregularities in the inner conductor.

7. A high frequency coaxial cable comprising a preformed flexible outer conducting tubing that forms one of the conductors of the coaxial circuit, the tubing substantially comprising a material that is capable of being uniformly stretched, an inner conductor centrally positioned within said tubing, said tubing being substantially free of bends of a character which would cause signal distortion in excess of a predetermined permissible amount in the coaxial circuit, said condition having been obtained by the application to the outer tubular conductor of a tensional force sufficient to stretch the same uniformly and remove therefrom bends of the aforesaid character which had been introduced into said conductor.

8. A high frequency coaxial cable comprising a flexible, seamless copper tubing that forms one of the conductors of the coaxial circuit, an inner conductor centrally positioned within said tubing, said tubing being substantially free of bends of a character which would cause signal distortion in excess of a predetermined permissible amount in the coaxial circuit, said condition having been obtained by the application of a tensional force to an end of the tubing sufficient to stretch the same uniformly and remove therefrom bends of the aforesaid character which had been introduced into said tubing.

9. A high frequency coaxial cable comprising a preformed flexible outer conducting tubing that forms one of the conductors of the coaxial circuit, the tubing substantially comprising a material that is capable of being uniformly stretched, said tubing being substantially free of bends, kinks and irregularities of a character which would cause signal distortion in excess of a predetermined permissible amount in the coaxial circuit and having a smooth inner circular configuration of uniform diameter substantially throughout the length thereof, said condition having been obtained by the application of a tensional force to the outer conductor sufficient to stretch the same uniformly and remove bends therefrom and by passage of a shaping device through said tubing to remove kinks and irregularities from the inner surface thereof, an inner conductor installed within said tubing, insulator pieces centrally supporting said inner conductor within the tubing, the inner conductor being sub-



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stantially free of bends, kinks and irregularities of a character which would cause signal distortion in excess of a predetermined permissible amount in the coaxial circuit, said condition having been obtained by the application of a tensional force to the inner conductor sufficient to stretch the same uniformly after its installation in said outer tubing.

10. A high frequency coaxial cable comprising a flexible, seamless copper tubing that forms one of the conductors of the coaxial circuit, said tubing being substantially free of bends, kinks and irregularities of a character which would cause signal distortion in excess of a predetermined permissible amount in the coaxial circuit and having a smooth inner circular configuration of uniform diameter substantially throughout the length thereof, said condition being obtained by the application of a tensional force to the outer conductor sufficient to stretch the same uniformly and remove bends therefrom and by passage of a shaping device through said tubing to remove kinks and irregularities from the inner surface thereof, an inner flexible, copper conductor installed within said tubing, insulator pieces centrally supporting said inner conductor within the tubing, the inner conductor being substantially free of bends, kinks and irregularities of a character which would cause signal distortion in excess of a predetermined permissible amount in

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the coaxial circuit, said condition having been obtained by the application of a tensional force to the inner conductor sufficient to stretch the same uniformly after its installation in said outer tubing.

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