Oct. 30, 1945. G. L. TAWNEY 2,387,783

TRANSMISSION LINE

Filed Feb. 1, 1943 2 Sheets-Sheet 1

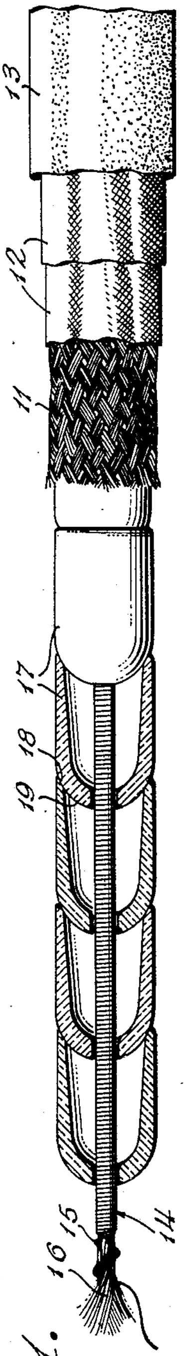

Fig. 1.

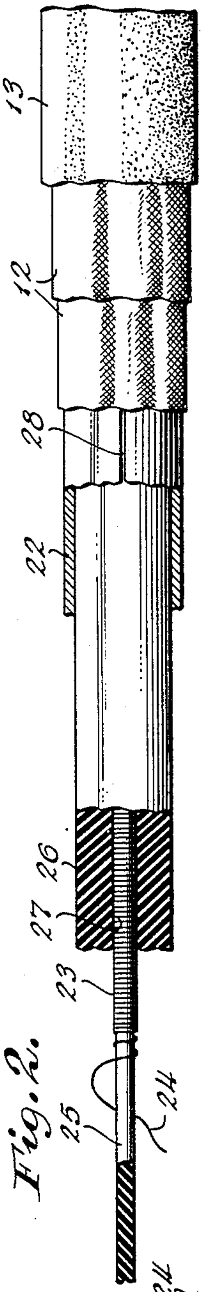

Fig. 2.

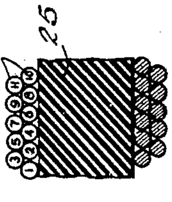

Fig. 2a.

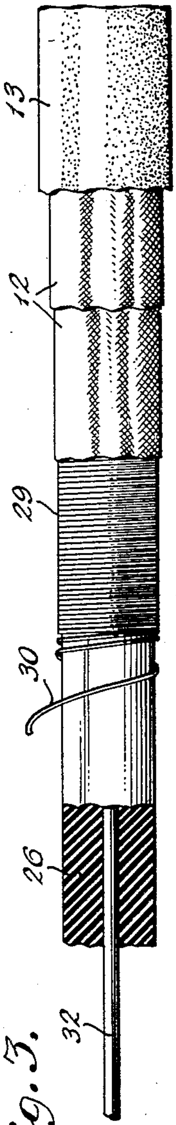

Fig. 3.

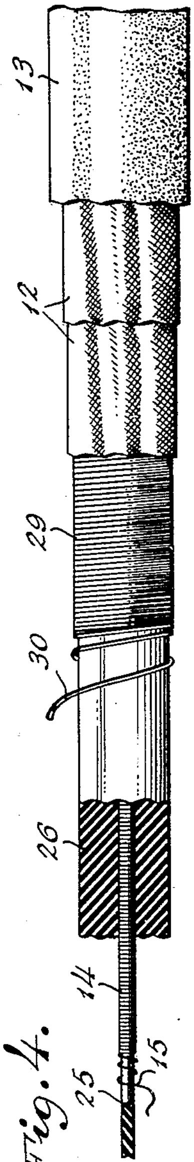

Fig. 4.

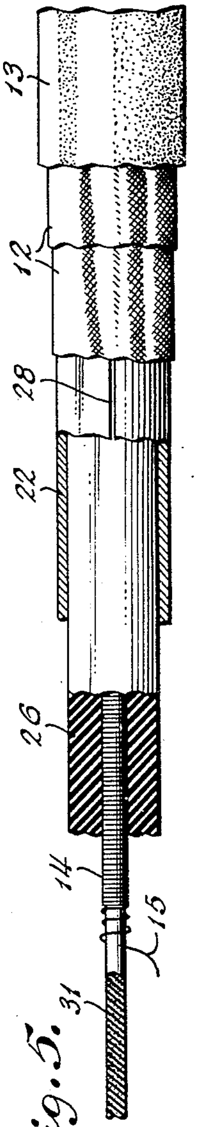

Fig. 5.

INVENTOR
Gereld L. Tawney
BY Paul B. Hunter.
ATTORNEY

Oct. 30, 1945. G. L. TAWNEY 2,387,783

TRANSMISSION LINE

Filed Feb. 1, 1943 2 Sheets-Sheet 2

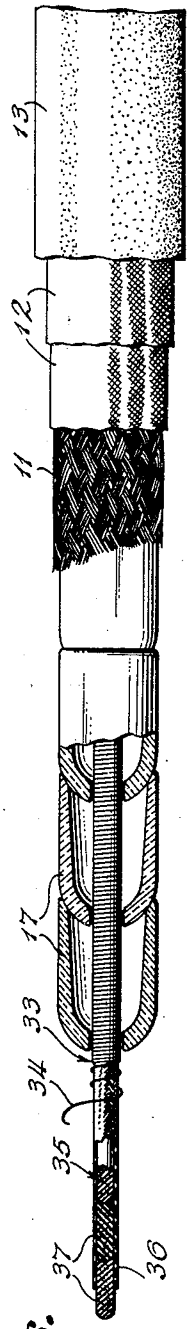

Fig. 6.

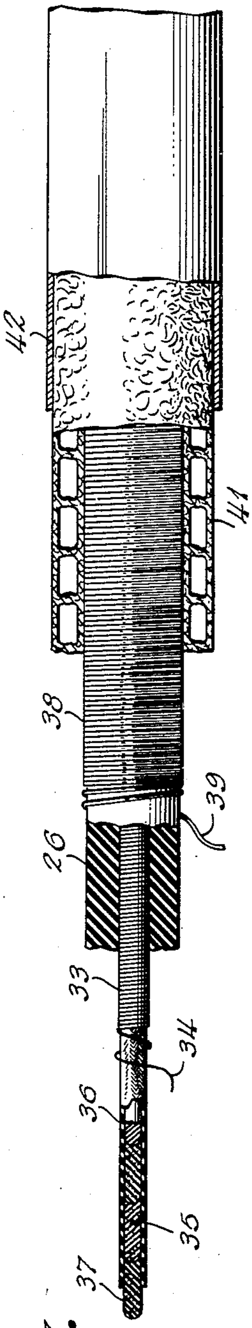

Fig. 7.

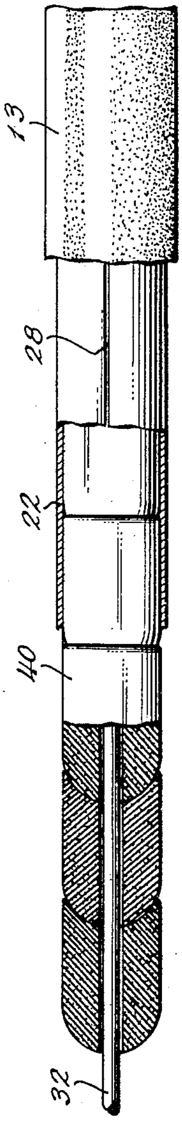

Fig. 8.

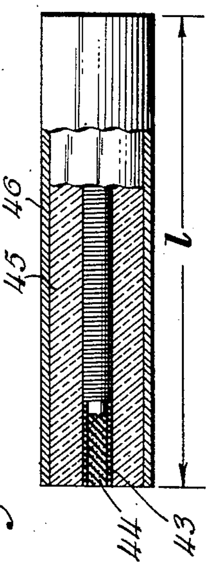

Fig. 9.

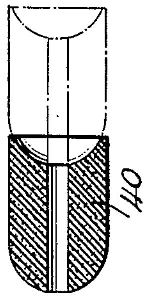

Fig. 10.

INVENTOR

Gereld L. Tawney

BY Paul B. Hunter.

ATTORNEY

Patented Oct. 30, 1945 **2,387,783**

UNITED STATES PATENT OFFICE

2,387,783

TRANSMISSION LINE

Gereld L. Tawney, Hempstead, N. Y., assignor to Sperry Gyroscope Company, Inc., Brooklyn, N. Y., a corporation of New York

Application February 1, 1943, Serial No. 474,400

32 Claims. (Cl. 178—45)

My invention relates to electrical transmission lines, and is particularly concerned with high impedance transmission lines for use in high frequency apparatus.

The invention will be described in its preferred embodiments as employed in coaxial transmission lines which are now used widely for distributing high frequency energy in pulse forming lines, and in delay lines.

Prior to my invention, coaxial transmission lines generally comprised chiefly a tubular outer conductor and a coaxial inner solid or stranded wire conductor supported and spaced within the tubular conductor by suitable insulating means. Most present day coaxial lines employ as the insulating means suitably formed members made of a low loss dielectric material such as polystyrene which is a polymerization product of styrene and is a thermoplastic adhesive resin having a fairly high dielectric constant.

These prior solid inner conductor coaxial lines have low characteristic impedance. For example in a coaxial line having an outer conductor diameter of about one-half inch and minimum practical size of inner conductor, the calculated characteristic impedance is only about 195 ohms. These prior coaxial lines have proven reasonably satisfactory for transmission lines requiring such low characteristic impedance.

However, for many purposes, demand has arisen for relatively high characteristic impedance coaxial lines. For example, in some installations, it is preferable to transmit signals made up of periodic pulses each having a duration of only a fraction of a micro-second over as much as 20 to 40 feet of coaxial line at impedance levels of about 1000 to 1500 ohms. Since the above described prior coaxial lines cannot by themselves attain such impedance levels, it has hitherto been necessary in such installations to supplement them with auxiliary equipment such, for example, as cathode follower apparatus requiring the use of vacuum tubes.

The invention contemplates coaxial transmission lines of revolutionary design for attaining desired high characteristic impedance levels, over a wide range of frequencies.

In general it may be stated that the characteristic impedance Z_k of a transmission line equals

$$\sqrt{\frac{L'}{C'}}$$

where L′ and C′ are inductance and capacitance values per unit length. Hence, the characteristic impedance of any such line can theoretically be increased either by decreasing its capacitance or increasing its inductance. I have studied various arrangements for decreasing the capacitance in coaxial lines, but none seem to offer the improvements obtained by arrangements for increasing inductance which comprise the preferred embodiments of my invention.

With the above in mind, it is a major object of my invention to provide a novel coaxial type transmission line having relatively high characteristic impedance.

A further object of the invention is to provide coaxial transmission lines of novel construction.

A further object of the invention is to provide a high characteristic impedance coaxial transmission line having novel arrangements providing high distributed inductance in the line. Preferably this high inductance is obtained by employing a coiled inner or outer conductor, or both, or cores of insulating material having high magnetic permeability within the coaxial line, or various combinations of coiled conductors and such cores.

A further object of the invention is to provide a novel coaxial type transmission line having one or both conductors disposed to provide relatively high distributed inductance.

A further object of my invention is to provide a novel manner of controlling impedance and time delay properties of a coaxial transmission line.

A further object of the invention is to provide a novel coaxial transmission line wherein at least one conductor, preferably the inner conductor, is a closely wound coil.

A further object of the invention is to provide a novel coaxial transmission line wherein a coiled inner conductor is disposed within a tubular outer conductor having a diameter bearing predetermined relation to the coil diameter for obtaining maximum characteristic impedance in the line.

A further object of the invention is to provide a novel delay line comprising a coaxial transmission line having inductive and capacity loading arrangements.

Further objects of the invention will presently appear as the description proceeds in connection with the appended claims and the annexed drawings wherein:

Fig. 1 is mainly a section through the center of a coiled inner conductor flexible coaxial transmission line embodying the invention;

Fig. 2 is mainly a section through the center of a semi-rigid coaxial transmission line similar to

Fig. 1 wherein the inner conductor is a closely wound coil;

Fig. 2*a* illustrates, in an enlarged diagrammatic section, the overlapped winding of Fig. 2;

Fig. 3 is mainly a section through the center of a coaxial transmission line having a coiled outer conductor;

Fig. 4 is mainly a section through the center of a coaxial transmission line wherein both inner and outer conductors are coiled;

Fig. 5 is mainly a section through the center of a coaxial transmission line wherein the inner conductor is a coil about a continuous core of relatively high magnetic permeability;

Fig. 6 is a section through the center of a coaxial transmission line according to another embodiment of the invention wherein the inner conductor is a coil closely wound about a sectional core of high magnetic permeability.

Fig. 7 is mainly a section through the center of a flexible coaxial transmission line having wound inner and outer conductors and special insulation and shielding arrangements.

Fig. 8 is mainly a section through the center of a flexible coaxial transmission line wherein increased distributed inductance is obtained simply by the use of a sectional core of high magnetic permeability between the conductors;

Fig. 9 is mainly a section through the center of a delay line according to the invention having both inductance and capacity loading arrangements; and

Fig. 10 is a side elevation, partly in section of a bead of the type used in Fig. 8.

In general, according to the invention, I preferably increase the characteristic impedance of a coaxial line by increasing the inductance of one or both of the conductors, as by coiling. Especially where one of the conductors is coiled, the inductance may be further appreciably increased by providing a core or cores of high magnetic permeability within the line. For example, the core may be within the coiled inner conductor, or between the outer conductor and the inner conductor. Any desired combination of coiled inner and/or outer conductors, and inner and/or outer cores may be employed.

Fig. 1 illustrates a flexible cable of circular cross-section made according to one embodiment of the invention. The outer conductor 11, which may be a flexible metal tube or of braided copper construction as shown, is externally covered by successive braided cord and rubber sheaths 12 and 13 and any other desired insulating and protective sheathing.

The inner conductor 14 is a coil of relatively small diameter of fine insulated wire 15 closely wound upon a low loss dielectric core 16 which may be a bundle of twisted glass fibers as illustrated. Coil 14 provides a relatively high uniformly distributed inductance which insures that the characteristic impedance of the line is proportionately high. The absolute inductance value of coil 14 may be obtained as desired, as by different winding and spacing arrangements of conductor 15, depending on the requirement of the purpose at hand. Coil 14 is relatively large in diameter as compared to the usual solid inner conductor of prior coaxial lines.

Coil 14 is supported coaxially within outer conductor 11 by means of a plurality of relatively short individually rigid insulator beads 17 which may be of any low loss dielectric material such as polystyrene. Each bead 17 is formed with substantially spherical convex nose and concave tail mating surfaces indicated at 19 and 18, respectively, whereby the beads are arranged in a universally jointed array within the cable. This permits the cable to be bent and manipulated as desired without injury to the insulation. Beads 17 are of known construction and are shaped to provide a minimum of solid dielectric material between the conductors, thus illustrating some prior efforts to increase characteristic impedance by reducing the distributed capacity.

My invention enables high characteristic impedance transmission and delay lines to be accurately designed for most purposes. Considering a coiled conductor as a long, single layer closely wound solenoid, its characteristic inductance may be expressed as (1) $L'=\mu\mu_0\,\pi(rn')^2$ henrys per meter, and its characteristic resistance as

$$R'=\frac{\rho 2\pi r n'}{\pi a^2} \tag{2}$$

—which, for a closely wound coil, reduces to $8\rho\, r(n')^3$ ohms per meter, where:

μ=the magnetic permeability of material adjacent the coil;

$\mu_0=4\pi\times10^{-7}$ henrys/meter, the magnetic permeability of free space in the meter-kilogram-second system of units;

r=the radius of the coil;

n'=number of turns per meter in the solenoid;

a=radius of the round wire in the solenoid (for a closely wound coil,

$$a=\frac{1}{2n'}\Big)$$

and

ρ=the resistivity of the wire in the solenoid.

The relation (1) above holds true for computing inductance of a coiled conductor of a coaxial line, provided the other conductor is not too close to the coil.

In any concentric conductor line, wherein $2r_1$ is the inside diameter of the outer conductor and $2r_2$ is the outside diameter of the inner conductor, the characteristic capacitance is:

$$C'=\frac{2\pi k k_0}{\log_e\left(\frac{r_1}{r_2}\right)} \tag{3}$$

farads per meter, where k is the dielectric constant of the material between the conductors; and $k_0=8.85\times10^{-12}$ farads per meter, the dielectric constant of free space in the meter-kilogram-second system of units.

Using now the known relations:

$$Z_k=\sqrt{\frac{L'}{C'}} \tag{4}$$

$$T'\text{(time constant)}=\sqrt{L'C'} \tag{5}$$

and

$$\alpha'\text{(attenuation)}=R'/2Z_k \tag{6}$$

we can compute properties of any coaxial line.

For example, consider the coaxial line having an outer conductor of inner diameter $2r_1$, and an inner coil conductor of outer diameter $2r_2$. In this line, material having a magnetic permeability μ is disposed between the coil and outer conductor and also within the coil; and the material between the coil and outer conductor has a dielectric constant k.

It follows from (1) to (6) that

$$(7)\qquad Z_k=\sqrt{\frac{\mu\mu_0 \log_e\left(\frac{r_1}{r_2}\right)}{2kk_0}}(r_2n')\text{ ohms}$$

$$(8)\qquad T'=\sqrt{\frac{2\mu\mu_0 kk_0}{\log_e\left(\frac{r_1}{r_2}\right)}}(\pi r_2 n')\text{ seconds per meter}$$

$$(9)\qquad \alpha'=8\rho(n')^2\sqrt{\frac{kk_0}{2\mu\mu_0 \log\left(\frac{r_1}{r_2}\right)}}$$

A comparison of computed and actually measured values for an exemplary coaxial line similar to that shown in Fig. 1 will now be given. This line has the following dimensions and characteristics:

$$\left.\begin{array}{l} r_1=.00394\text{ meter} \\ r_2=.00075\text{ meter}\end{array}\right\}\left(\frac{r_1}{r_2}\right)=5.25$$

a=No. 38 wire diameter

$n'=5600$ turns/meter

$\rho=1.7\times10^{-8}$ ohms/meter (copper wire)

$k\doteq1.35$ (polystyrene outer beads)

$\mu\doteq1$ (polystyrene beads and glass fibers)

A comparison of calculated and measured characteristics give the following values:

Property	Computed	Actual measurements
C'	45.0×10^{-12} farads	44.9×10^{-12} farads.
L'	70 microhenrys	60.7 microhenrys.
R'	13.2 ohms	57.7 ohms (high because of spaced windings).
Z_k	1246 ohms	1160 ohms.
T'	.056 microsecond/meter	.0522 microsecond/meter.
α'	.0053 (theoretical minimum) neper/meter.	.0249 neper/meter.

The above measurements show clearly that the important properties of characteristic impedance and time constant may be closely designed in a transmission or delay line. The attenuation may be improved by closer winding of the coiled conductor. Equation 7 shows that Z_k may be best improved by changes in μ and r_2, while Equation 8 shows that T' may best be improved by changes in μ, k and r_2. The number of turns in the coil cannot be increased very far because it may cause the attenuation to become too high. The value of r_1 is limited by practical considerations, but r_2 may be varied over wide limits.

Tests and computations have shown that a maximum characteristic impedance is obtainable in such a line when the outer diameter of the inner conductor coil is spaced at least a minimum distance from the inner periphery of the outer conductor. According to my invention, maximum characteristic impedance is obtainable when the ratio of the inner conductor coil external diameter to an outer non-slitted conductor internal diameter is approximately 0.6. Where the conductor is slit, as in Fig. 2, the ratio may be higher.

Fig. 2 illustrates the principles of Fig. 1 as applied to a relatively rigid or semi-rigid coaxial line having the outer conductor **22** formed as a longitudinally continuous tube of copper or the like. The inner conductor is a coil **23** of relatively fine insulated wire **24** closely wound about a continuous solid rod or form **25**. I have found that high inductance may be obtained by winding wire **24** in such manner as to form a multi-layer coil, as by back winding wire **24** at intervals to overlap one or more previously wound turns, such as shown in Fig. 2*a*, the numerals **1–11** indicating the successive windings of wire **24**. Any suitable manner of winding wire **24** to form multi-layer coil **23** which has higher uniformly distributed inductance than a single layer coil is intended to be included herein.

Coil **23** is supported within the line by a continuous insulator sleeve **26** which fits snugly within outer conductor **22** and has a central passage **27** through which the inner conductor extends. If desired, to reduce capacity along the line, dielectric sleeve **26** may be replaced by spaced beads capable of equivalent support and insulating characteristics.

Rod **25** and sleeve **26**, in this phase of the invention are preferably of a low loss dielectric material similar to beads **17** of Fig. 1 where a rigid line is desired. Alternatively, rod **25** and sleeve **26** may be of a flexible dielectric material where a flexible line is desired. Rod **25** and sleeve **26** function only as insulators or winding forms in this embodiment. Solid metal tube **22** provides a better conductor than braided conductor **11**. When current is flowing through coil **23**, currents are induced in outer conductor **22**. In order to reduce these induced currents and to increase the ease of obtaining high impedance, I preferably form conductor **22** with a continuous narrow longitudinal slot **28** which interrupts the induced current paths. Where such a slitted outer conductor is employed, higher overall characteristic impedance of the line may be readily obtained.

Fig. 3 illustrates a coaxial transmission line wherein outer conductor **29** is a coil of insulated wire **30** closely wound upon an insulating sleeve **26** through which passes a solid center conductor wire **32**. Sleeve **26** is preferably of the same material as sleeve **26** of Fig. 2 and may be rigid or flexible as desired. Coil **29** provides considerable uniformly distributed inductance which makes the illustrated line of relatively high characteristic impedance.

Fig. 4 illustrates a coaxial transmission line wherein both inner and outer conductors are coiled, thereby combining certain features of Figs. 2 and 4. Care should be taken that the respective coils are so wound as to be additive; in other words, so that their combined effect is to provide a higher distributed inductance than either alone.

In the above described embodiments of Figs. 1–4, increased inductance is obtained by coiling one or both conductors, without other expedients. With regard to the remaining forms of the invention substitute and supplementary means for increasing the inductance will be disclosed.

Fig. 5 illustrates a coaxial line wherein the inner conductor wire **15** is wound upon continuous core rod **31** and the coil **14** extends through insulator sleeve **26** within the outer conductor, similarly to Fig. 2. The coaxial line of Fig. 5 differs from that of Fig. 4 chiefly in that rod **31**, instead of being the usual low loss dielectric, is composed of a material which has equivalent insulating properties but in addition has high magnetic permeability. Like rod **25**, rod **31** may be rigid or flexible as desired.

This material of rod **31**, according to a very satisfactory reduction to practice of the invention, may comprise a suitable binder, such as Bakelite, containing powdered iron or other highly magnetic material liberally dispersed therein. Core **31**, more generally therefore, preferably comprises finely powdered or granular iron or its equivalent distributed uniformly through a binder having the required insulating strength. This material will hereinafter be described as carbonyl iron material.

In explanation of the improved result, apparently the powdered iron core provides effective paths of high permeability greater than 1 for magnetic lines of force within the cable, similar to the effect of adding an iron core to an inductance coil, thereby increasing the overall inductance of the cable. Referring back to the above equations, it is seen that here I vary μ, which was stated to be one of the best factors variable for improving Z_k. The inductance may be increased by increasing the core diameter, but this consideration is limited by the practical conductor diameter ratio above given.

According to my invention the use of such high magnetic permeability cores enables the construction of a coaxial line having minimum losses for a given characteristic impedance during an appreciable range. Since the core increases the distributed inductance of the coil, I am enabled to use relatively large diameter wire for the coil winding in this embodiment, thereby keeping the ohmic losses low while obtaining a required high inductance.

As desired, sleeve 26 may be of the same low loss dielectric material as sleeve 26 in Fig. 2, or may be made of the same material as core 31. This latter construction further increases the distributed inductance in the line. Another variation of the line in Fig. 5 is to replace core 31 with a polystyrene rod 25, while sleeve 26 only is of carbonyl iron material. This provides a high characteristic impedance cable available for obtaining certain impedance values.

A flexible coaxial line capable of very high characteristic impedance is shown in Fig. 6, where the outer conductor and insulating bead arrangements are the same as in Fig. 1, but wherein the inner conductor 33 comprises a coil of insulated fine wire 34 tightly and closely wound about a sectional core 35 of high magnetic permeability enclosed in a tubular sheath 36 of braided glass fibers. Conductor 33 extends through a series of beads 17 similarly to Fig. 1.

Each section 37 of core 35 is a relatively short carbonyl iron bead of the same material as core 31 of Fig. 5. In coaxial lines successfully built and tested, beads 37 are slightly less than ⅛ inch in diameter and about ⅜ inch long. The ends of beads 37 are surfaced for universally jointed contact, similarly to beads 17, and the beads are threaded and held together in alignment within a flexible fiber glass braided tubing on which No. 40 insulated wire is closely wound. The inside diameter of outer conductor 11 is in the neighborhood of ⅜ inch. With outer beads 17 of polystyrene, the characteristic impedance of this line has been measured to be about 3500 ohms.

Fig. 7 illustrates a further available form of coaxial line which the invention may take. The inner conductor 33 is wound about a sectional carbonyl iron core as in Fig. 6, and is located within continuous insulating sleeve 26 which may be of a low loss dielectric material as in Fig. 4, or of the same material as core 31 in Fig. 5, depending on the characteristic impedance value desired.

The outer conductor 38 is a coil of insulated wire 39, preferably wound in multi-layer arrangements similarly to Fig. 2*a*.

The coaxial line of Fig. 7 is enclosed within a relatively thick insulating sleeve 41, which may be of cellular construction as shown, and the whole is enclosed within a continuous metal shielding tube 42 which protects the line both electrically and mechanically.

The coaxial line of Fig. 8 is similar in construction to the prior solid inner conductor coaxial lines above discussed, but differs therefrom in that universally contacting beads 40 of carbonyl iron material are employed. As shown also in Fig. 10, beads 40 are of such shape and cross-section as to provide maximum solid core material between the conductors. Simply by employing these special insulator beads in such a coaxial line, I am enabled with currently available carbonyl iron material to raise the characteristic impedance of the line by a factor of about two. Tests on a coaxial line of this construction have shown the upper limit of characteristic impedance to be in the neighborhood of 500 ohms.

Other useful forms of the invention are in coaxial lines wherein the conventional polystyrene beads 17 in Figs. 1 and 6, and sleeve 26 in Figs. 2–4 and 7, are replaced by carbonyl iron beads 40 of the type shown in Fig. 10, so that these beads comprise effectively external or internal cores for the inner conductor, as the case may be. Using carbonyl iron outer beads in the cable of Fig. 6, for example, I am able to produce coaxial lines having characteristic impedance values as high as 20,000 ohms or more, with No. 46 wire on the inner coil conductor.

In general any of the above arrangements described in Figs. 1–8 may be used singly or in combination, depending on the desired inductive loading. Given the desired characteristic impedance of the required line, the above principles are employed in calculating and building a line of best practical construction. I have found that use of carbonyl iron cores and beads, besides increasing the inductance, increases the line capacity slightly which decreases the characteristic impedance.

By varying the powdered iron content in core 31 and in beads 37 or 40, it is possible to vary the effect of such material in the cable and thereby control the characteristic impedance values within desired limits. However, as a practical matter, with currently available carbonyl iron material it is usually desirable to employ cores and beads of maximum iron content, which accounts for the shape of bead 40. The above described coaxial transmission lines have proved satisfactory for intended purposes. Tests at frequencies up to 5 megacycles show that the lines transmit without noticeable distortion square wave pulses having about 0.1 microsecond rate of rise and about 0.5 microsecond duration. The attenuation losses up to 5 megacycles, at least, are not measurably different from direct current resistance losses, although for higher frequency they increase more rapidly. Eliminating the powdered iron cores for higher frequencies, it appears that satisfactory operation up to beyond 40 megacycles is possible.

Further, since the coaxial line construction of the invention comprises definite inductive and capacitance loading, the coaxial line may be employed as an accurate delay line having a uniform time constant per unit length. For example, a coaxial line similar to Fig. 3 was found to have a delay constant of 0.67 microsecond per foot.

Fig. 9 illustrates the invention as applied to construction of a coaxial conductor delay line having an appreciable time constant per unit length. Here the center conductor 43 is a coil of insulated fine wire wound about a solid rod **44** of carbonyl iron or the equivalent for inductive loading. Coil **43** is mounted snugly within the central passage of a solid sleeve **45** of some material having a very high dielectric constant. For example, I have found an oxide of titanium commonly known as rutile to be very satisfactory, and this material has a dielectric constant of about 40 to 60 times as large as polystyrene. The outer conductor is a metal tube **46** enclosing sleeve **45**, and a suitable shielding covering may be used as desired.

Since the rutile sleeve introduces a considerable capacitance factor into the line, the line is loaded both inductively and capacitatively. The time constant T' for such a line is equal to

$$l\sqrt{L'C'}$$

where l is the length of the line, so that choice of a suitable length of line can be made to produce an appreciable desired delay in transmission of pulses or the like along the line. In accord with the general mathematical discussion of the invention above, a delay line of substantially any desired value can be designed utilizing the principles of the invention.

As many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description as shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a transmission or delay line, an inner conductor, a substantially concentric outer conductor, said conductor being electrically insulated, and means physically distributed substantially uniformly along and within said line providing high characteristic impedance comprising insulating core means of magnetic permeability substantially greater than air disposed between said electrically insulated conductors.

2. The transmission or delay line defined in claim 1, wherein said physically distributed means comprises also the formation of one of said conductors as a coil having turns insulated from each other substantially coaxial with the other conductor.

3. In a coaxial type transmission line, an outer conductor, an inner conductor extending through said outer conductor, and means distributed substantially uniformly along and within said line for providing high inductance for at least one of said conductors comprising insulating core means of magnetic permeability substantially greater than air disposed between said conductors.

4. In a coaxial type transmission line, an outer conductor and a spaced inner conductor, said conductors being electrically insulated and at least one of said conductors being formed to provide substantially uniformly distributed high inductance along said line, and insulating core means having magnetic permeability substantially greater than air disposed between said electrically insulated conductors.

5. In a coaxial type transmission line, an outer conductor and an inner conductor, at least one of said conductors being in the form of a substantially uniform diameter closely wound coil of insulated wire having relatively high inductance, and insulating means within said line spacing said conductors.

6. A coaxial type high frequency transmission line section of high characteristic impedance comprising an outer conductor, an inner conductor comprising a substantially uniform diameter closely wound coil of insulated wire, and insulating means spacing said conductors within said line.

7. A coaxial type high frequency transmission line section of high characteristic impedance comprising an inner conductor, an outer conductor comprising a substantially uniform diameter closely wound coil of insulated wire, and insulating means spacing said conductors within said line.

8. A coaxial type high frequency transmission line section of high characteristic impedance comprising an inner conductor and an outer conductor, each of said conductors comprising a substantially uniform diameter closely wound coil of insulated wire, an insulating means spacing said conductors within said line.

9. The transmission line section defined in claim 8, wherein said coiled conductors are additively wound so that combined they produce a higher distributed inductance than either alone.

10. A transmission line comprising substantially coaxial inner and outer conductors, at least one of said conductors being in the form of a substantially uniform diameter coil of insulated wire having relatively high inductance, and insulating means within said line between said conductors, said insulating means comprising a material having higher magnetic permeability than air.

11. In a coaxial type transmission line, an outer conductor, and a coiled inner conductor, said conductors being substantially circular and the outer diameter of said coil being less than approximately 0.6 the inner diameter of said outer conductor.

12. In a coaxial type transmission line, an outer conductor, an inner conductor of appreciably smaller diameter than said outer conductor extending through said outer conductor, and an insulating body having higher magnetic permeability than air within said line disposed adjacent at least one of said conductors.

13. The transmission line defined in claim 12, wherein said body contains substantially uniformly dispersed powdered ferromagnetic material.

14. In the transmission line defined in claim 12, wherein said body comprises powdered iron dispersed in a binder of Bakelite or the like.

15. A transmission line comprising an outer conductor, an inner conductor comprising a coil of insulated wire closely wound about an insulating core, and a body of insulating material having a magnetic permeability substantially greater than air mounted within said line between said conductors.

16. The transmission line defined in claim 15, wherein said insulating core also comprises a body of insulating material having a magnetic permeability substantially greater than air.

17. In a transmission line, an outer conductor, an inner conductor comprising a coil having its turns insulated from each other substantially coaxial with said outer conductor, a core of a material having higher magnetic permeability than air associated with said coil within said line, said core comprising a succession of individually rigid universally coupled sections.

18. In a transmission line, an outer conductor, an inner conductor insulated from said outer conductor and comprising a coil substantially coaxial with said outer conductor and having its turns insulated from each other, a core comprising a suc-

cession of beads within said coil, said beads being of a material which has higher magnetic permeability than air.

19. The transmission line defined in claim 18, including a tubular sheath of insulating material in which said beads are mounted and about which said coil is wound.

20. For use in a high frequency coaxial conductor transmission line; a body of paramagnetic insulating material, and coupling surfaces formed on opposite ends of said body for closely but universally relatively movably fitting with similarly formed bodies when arranged in close succession therewith in said line, said body being substantially solid and axially apertured in close conformity to the periphery of a conductor passing therethrough, so that said body provides a maximum cross-section of said material along the line.

21. A flexible high frequency transmission line comprising substantially flexible inner and outer conductors and paramagnetic core means disposed between said conductors comprising an axial succession of individually rigid sections having adjacent ends universally mated and connected so as to permit flexing of said line.

22. In a coaxial type transmission line having appreciable delay properties, a tubular outer conductor, a coiled inner conductor, an insulating core containing dispersed ferromagnetic material for said inner conductor, said core and coil providing a substantially uniformly distributed high inductance along said line, and a sleeve of a material having a high dielectric constant between said conductors, said sleeve providing a substantially uniformly distributed high capacity along said line.

23. A flexible high frequency transmission line comprising substantially coaxial flexible inner and outer conductors, one of said conductors comprising a closely wound coil of insulated wire, and core means associated with said coil within said line comprising an axial succession of individually rigid sections of an insulating material having higher magnetic permeability than air, said sections having adjacent ends so connected as to permit flexing of the line.

24. The transmission line defined in claim 23, wherein said inner conductor is the coiled conductor, and said core is disposed within said inner conductor.

25. The transmission line defined in claim 23, wherein said inner conductor is the coiled conductor, and said core is disposed between said conductors.

26. The transmission line defined in claim 23, wherein said outer conductor is the coiled conductor, and said core is disposed between said conductors.

27. A flexible high frequency transmission line comprising substantially coaxial flexible inner and outer conductors, each of said conductors being a closely wound coil of insulated wire, flexible insulating means spacing said conductors, and a flexible core within said inner conductor comprising a contacting succession of individually rigid sections of an insulating material having higher magnetic permeability than air.

28. The transmission line defined in claim 27, wherein said flexible insulating means comprises a succession of contacting individually rigid sections of an insulating material having higher magnetic permeability than air.

29. A flexible high frequency transmission line comprising substantially coaxial flexible inner and outer conductors, each of said conductors comprising a coil of insulated wire wound upon a flexible insulating core, the core between said conductors comprising a contacting succession of individually rigid sections of an insulating material having higher magnetic permeability than air.

30. A high frequency transmission line comprising substantially coaxial inner and outer conductors, one of said conductors comprising a continuous coil of insulated wire wound with certain turns overlapping one or more previously wound turns so that said coil provides a high distributed inductance along said line, and insulating means spacing said conductors.

31. In a transmission line, an inner conductor comprising a coil of insulated wire, a longitudinally slotted outer conductor insulated from said inner conductor and supported substantially coaxially with said inner conductor, and a core comprising a succession of paramagnetic beads within said coil.

32. A flexible high frequency transmission line comprising substantially coaxial flexible inner and outer conductors insulated from each other, one of said conductors comprising a coil of insulated wire wound upon a flexible insulating core, a further core between said conductors comprising a contacting succession of individually rigid paramagnetic sections, and a cellular insulating sleeve enclosed within a metal shielding tube.

GERELD L. TAWNEY.