United States Patent

Miller et al.

[15] **3,671,662**

[45] **June 20, 1972**

[54] **COAXIAL CABLE WITH FLAT PROFILE**

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[22] Filed: **Dec. 16, 1970**

[21] Appl. No.: **98,787**

[52] **U.S. Cl.** ....**174/28,** 174/16 B, 174/99 B, 174/117 F, 333/96 R

[51] **Int. Cl.** **H01b 9/04**

[58] **Field of Search**.............174/28, 29, 27, 24, 16 B, 117 F, 174/117 FF, 117 R, 117 AS, 113 AS, 113 R, 133, 119, 99 B; 333/95 R, 96 R

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Assistant Examiner—A. T. Grimley
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[57] **ABSTRACT**

A flattened coaxial cable structure has been found to exhibit advantages over conventional circular coaxial structures for some applications. This structure is a bifurcated conventional coaxial cable with the two semicircular segments joined by flat solid metal. A wide range of impedances can be realized without any significant penalty in added loss. Furthermore, tolerances to achieve certain design objectives, such as attenuation deviation, may be appreciably relaxed with the new structure.

6 Claims, 16 Drawing Figures

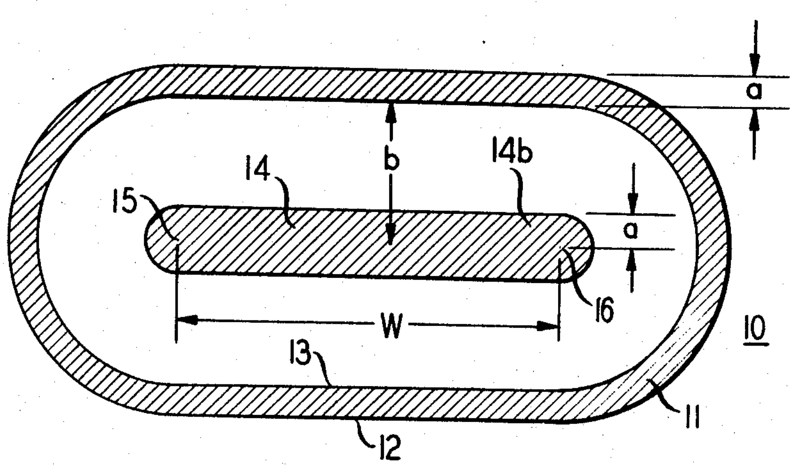

FIG. 1A

PRIOR ART

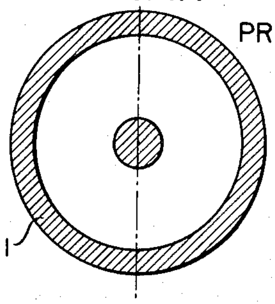

FIG. 1B

PRIOR ART

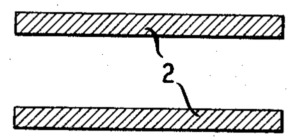

FIG. 1C

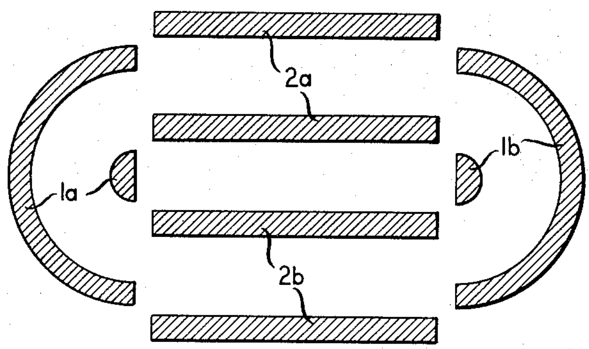

FIG. 2

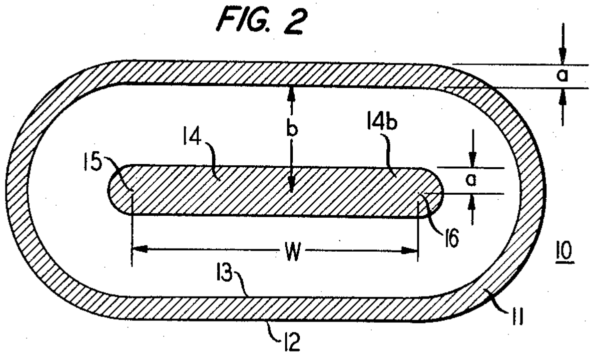

FIG. 2A

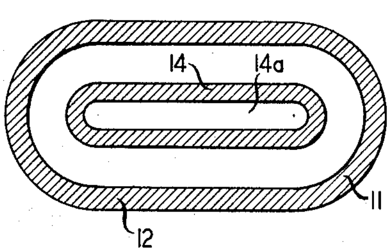

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FIG. 3

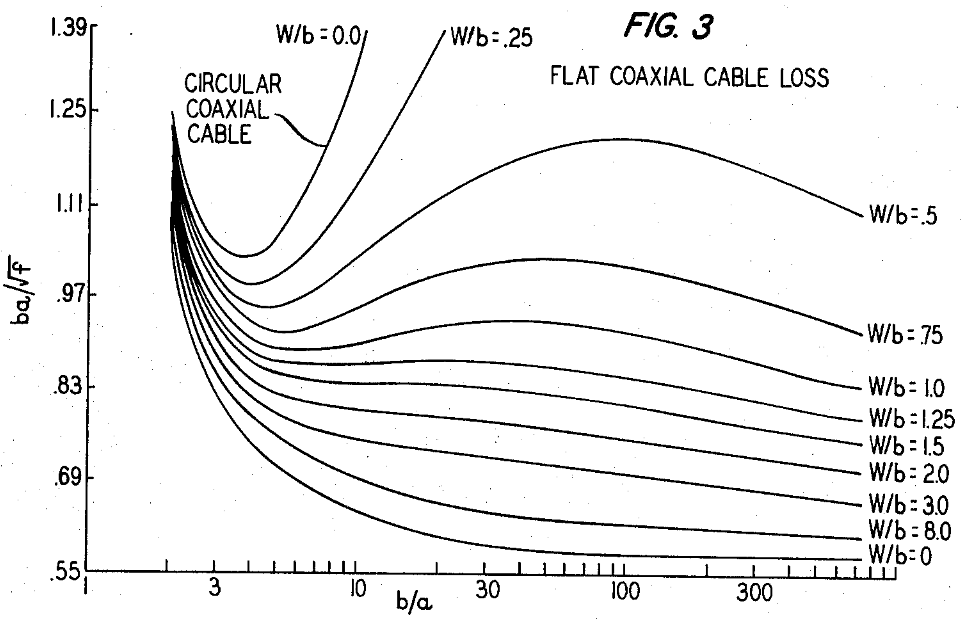


FIG. 4

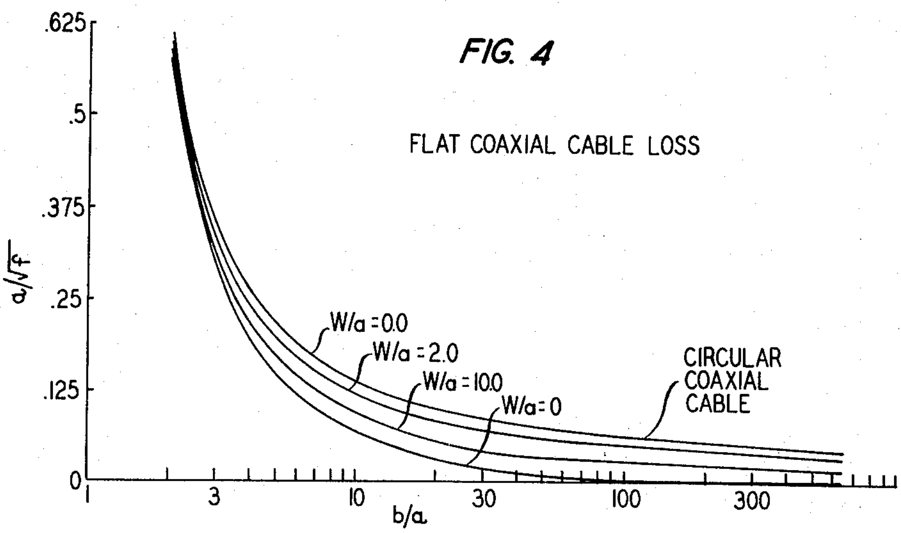


FIG. 6

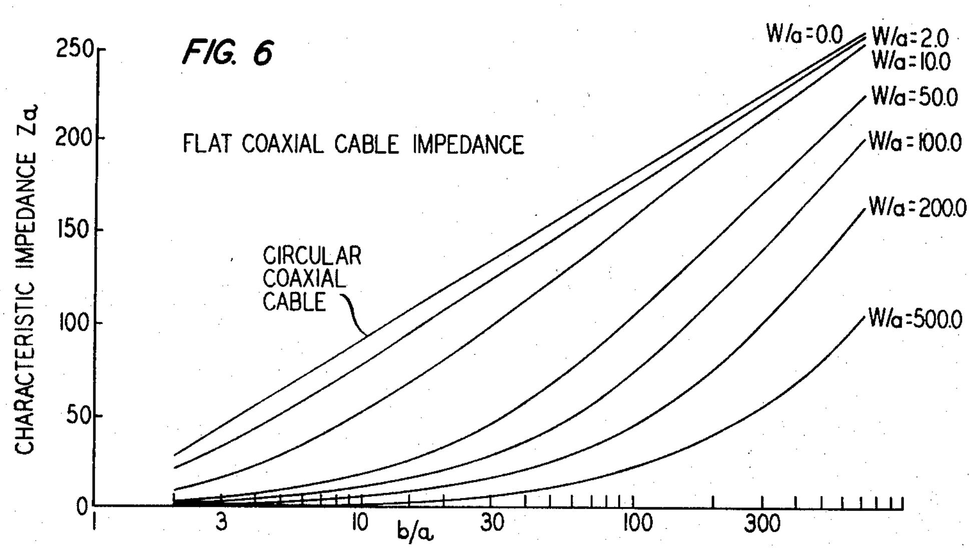


FIG. 5

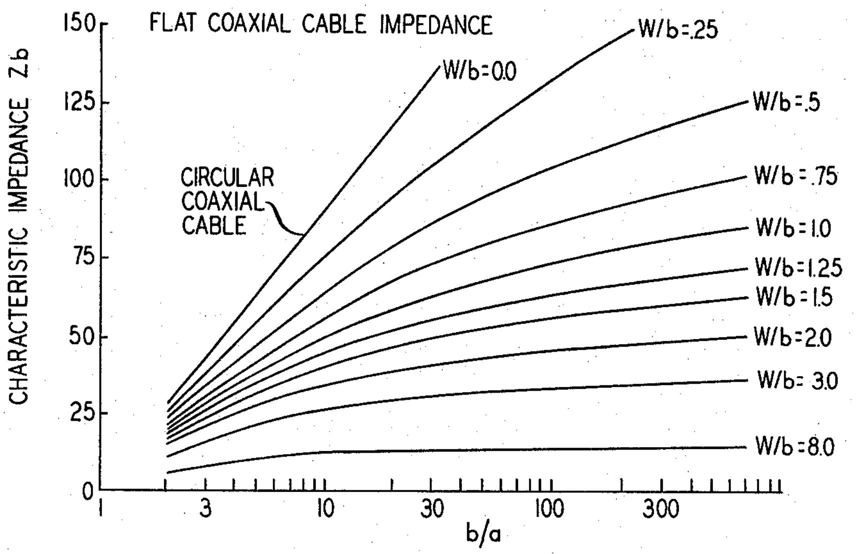


FIG. 7

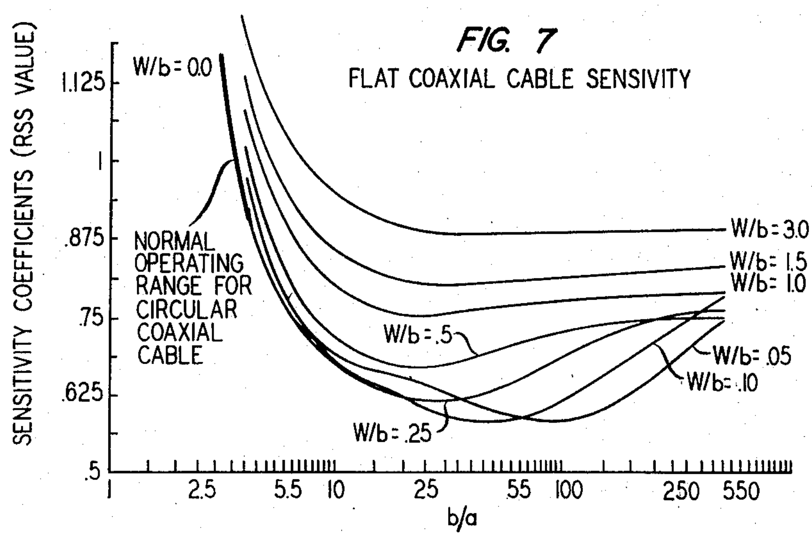


FIG. 8

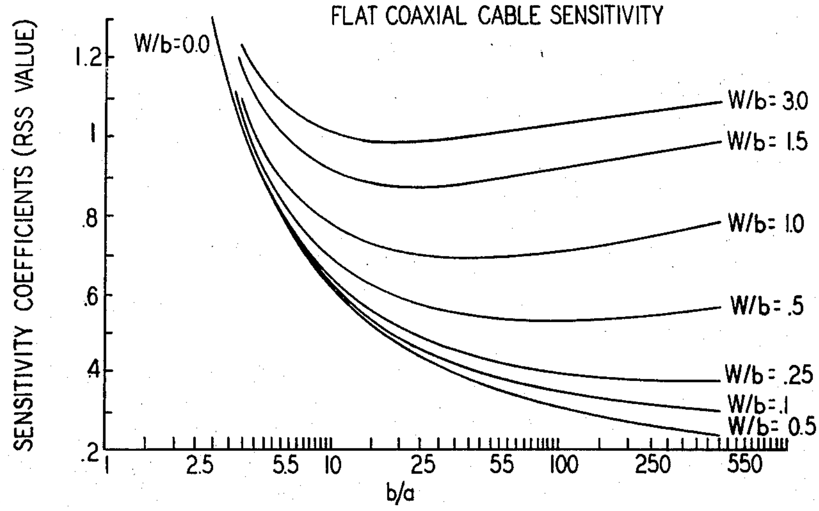


FIG. 13

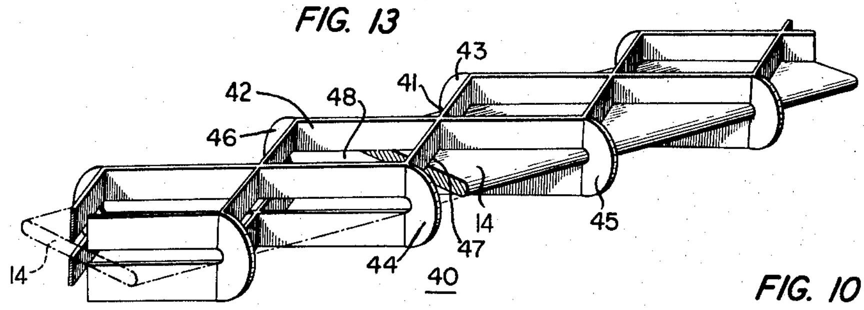


FIG. 10

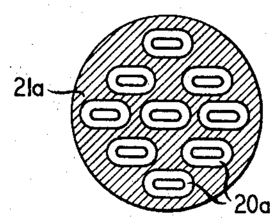


FIG. 9

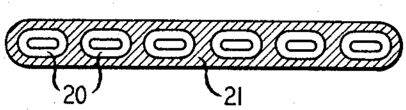


FIG. 11

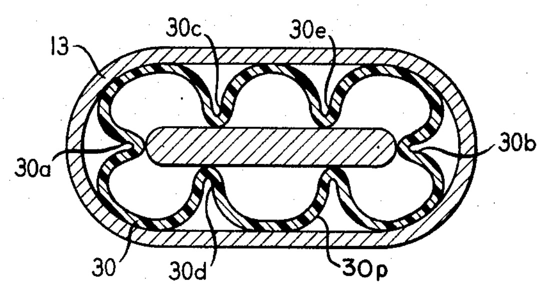
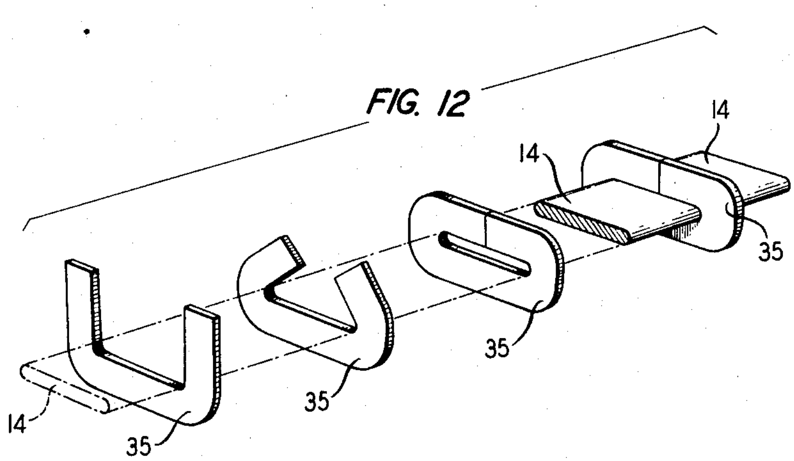


FIG. 12



COAXIAL CABLE WITH FLAT PROFILE

FIELD OF THE INVENTION

This invention relates to coaxial cable structures in general and particularly to such a structure comprising flattened top and bottom portions.

BACKGROUND OF THE INVENTION

Numerous coaxial cable designs exist which attempt to take advantage of the skin effect. The skin effect considerations prompted applicants to consider designs that would increase the effective surface area of the conductors at high frequencies.

One object of the invention is to achieve savings in material costs in a coaxial cable to be used at high frequencies.

A further object of the invention is to provide a coaxial cable structure that at low frequencies exhibits a self-equalizing property.

SUMMARY OF THE INVENTION

As will be shown in detail in the description to follow, our coaxial cable structure is characterized by an outer conductor having rounded sides joined by flat, elongated top and bottom portions. This flat coaxial cable transmission line (FCC) is further characterized by an inner and an outer conductor whose opposing surfaces are maintained at a uniform, constant mutual separation. This separation may be denoted $b-a$ where a is the radius of curvature of the outside surface of the inner conductor and b is the radius of curvature of the inside surface of the outer conductor. The opposing surfaces consist of the two semicircular end portions joined by flat portions of a width w. The advantageous operating range of the overall structure is specified by the relationships: $b/a > 10$ and $w/b < 1.5$.

A feature of our invention, therefore, resides in the flattened, elongated top and bottom portions of a coaxial cable.

A further feature of the invention is in spacing arrangements for such a coaxial cable structure.

The invention, and its further objects, features, and advantages will be readily discerned in full from a reading of the description to follow of an illustrative embodiment taken in conjunction with the drawing.

DESCRIPTION OF THE DRAWING

FIGS. 1A, 1B and 1C are schematic diagrams showing the structural evolution of coaxial cable into the flat coaxial line of FIG. 2, and FIG. 2A.

FIGS. 3–8 are graphical portrayals of various comparative relationships exhibited in circular coaxial versus flat coaxial lines.

FIGS. 9 and 10 are schematic cross-sectional diagrams of multiple jacketed flat coaxial structures; and

FIGS. 11, 12, and 13 are various schematic diagrams of spacers designed for the present invention.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

FIG. 1A shows a cross section of a standard coaxial line **1**, and FIG. 1B a cross section of a parallel transmission line **2**. FIG. 1C depicts the combining process of two parallel transmission lines **2*a*** and **2*b*** in a bifurcated coaxial line whose sections are designated **1*a*** and **1*b***.

FIG. 2 depicts in cross section the resulting flat coaxial cable line designated generally **10**. The line **10** consists of an outer conductor **11** having an exterior surface **12** and an interior surface **13**. The inner conductor is denoted **14**, with exterior surface **14*b***.

As seen in FIG. 2, the top and bottom portions of both outer conductor **11** and inner conductor **14** are flat within the region denoted w. The radius of curvature of the two end portions of inner conductor **14** is denoted a, and the radius of curvature of the interior surface of the two end portions of outer conductor **11** is denoted b. At either end, these curvature radii are struck from a common center, denoted **15** at the left-hand end and **16** at the right-hand end. The resulting structure is shaped like a racetrack in which the opposing surfaces **13**, **14*b*** experience a constant uniform separation along all points of the structure.

The flat coaxial cable structure may also be thought of as a circular structure in which the inner conductor has been hollowed out and then both inner and outer conductors flattened as described above. It will be appreciated that the flattening operation, for cables having a diameter greater than a few tenths of an inch, does not increase the attenuation nearly as much as it decreases the area of the inner conductor. The material saved can be used in part to increase the total area embraced by the outer conductor, which decreases the attenuation to less than the figure which obtained before the flattening. Hence, a lower attenuation and a net savings in cost of materials results. Of course, both flattening and hollowing out achieve a further savings in materials. FIG. 2A shows a flattened coaxial cable structure with the inner conductor hollowed out, the hollowed out portion being denoted by the numeral **14*a***.

The below equations are directed to high-frequency relationships that show attenuation increasing as the square root of frequency. At lower frequencies where $f << (2.614/a)^2$ and the conductors are electrically thin, flattened coaxial cable exhibits a self-equalizing property. That is, the attenuation is constant with frequency up to a transition frequency. This characteristic is potentially advantageous in digital systems where a flat response would yield good pulse transmission. The transition frequency can be increased by decreasing the thickness of the inner and outer conductors.

Multicoax cables consisting of plurality of flattened coaxial cables, as described above, are depicted in FIGS. 9 and 10. In FIG. 9, a plurality of flattened coaxial cable units or structures, each designated **20**, are disposed in a line with their inner conductor centers lying in substantially the same plane. Advantageously, the edges of adjacent structures are not in contact. An extruded jacket **21** of, for example, polypropylene, is placed over the flattened coaxial cable structures **20**. The resulting ribbonlike structure will bend more readily than a similar structure consisting of circular coaxial cables since for the same α and Z_0 the thickness is less. Further, crosstalk is normally reduced because the inner conductor midpoints are spaced a greater distance than for the corresponding conventional circular coaxial cable.

FIG. 10 depicts a multiplicity of flattened coaxial cable structures, denoted **20*a***, in a diamond configuration that approximates a circle in cross section. The structures **20*a*** are not in edge contact. An extruded jacket **21*a*** is placed around the assembly. In the configuration of FIG. 10, the flattened portions of structures **20*a*** advantageously are parallel to one another.

Spacing of the inner and outer conductors as well as support for the inner conductor are achieved pursuant to the following further inventive embodiments.

In FIG. 11 the inner conductor **14** is spaced from the outer conductor **13** by means of an insulating layer **30** which has been longitudinally undulated or crimped in six places as shown. The layer is continuous advantageously along the entire length of the structure, its cross section being depicted as in FIG. 11. Specifically, two end crimps **30*a***, **30*b***, contact the ends of the inner conductor **14**. The opposing crimps **30*c***, **30*d***, contact the top and bottom surfaces respectively of inner conductor **14** adjacent to the crimp **30*a***. Similarly, the crimps **30*e***, **30*f***, contact the top and bottom surfaces of inner conductor **14** adjacent to the crimp **30*b***. The insulating material advantageously is a plastic such as polypropylene.

Another form of spacer is shown in FIG. 12. A U-shaped staple **35** is placed around the inner conductor **14**, and then by stages formed into a racetrack-shaped spacer. These operations occur in advance of placing the inner conductor within the outer conductor.

A lattice-type spacer is depicted in FIG. 13. This spacer, denoted **40**, comprises basically a pair of legs **41**, **42** intersecting in lattice fashion at their lengthwise midpoints. The respective ends **43**, **44** and **45**, **46** are semicircular in shape, and are offset with respect to the legs **41** so that the ends **43**, **45** fall in a common plane and the ends **44**, **46** fall in another common plane which is parallel to that of ends **43**, **45**. Lengthwise down the entire midsection of the legs **41**, **42** are slits **47**, **48**. These are slightly wider than the width of inner conductor **14**.

As seen in FIG. 13, a number of spacers **40** are combined as end-to-end units and mounted upon the inner conductor **14**. The legs **41**, **42** each straddle-mount the inner conductor **14**, with their top and bottom sides normal to the top and bottom surfaces of inner conductor **14**; and are oriented obliquely, rather than perpendicularly, to the central axis. By virtue of the oblique orientation of each leg **41**, **42** with respect to the inner conductor central axis, it is seen that inwardly directed forces on the ends **43**, **45** and ends **44**, **46** bring the ends of slits **47**, **48** into firm contact with the edges of inner conductor **14**. In this position, the ends **43–46** are substantially perpendicular to the central axis and also to the flattened surface of inner conductor **14**. The spacer provides honeycomblike support of the outer conductor, as well as positive central spacing of the inner conductor with respect thereto.

The benefits of the inventive flat coaxial cable structure were further revealed from the following analysis.

For coaxial and parallel transmission lines, the high frequency secondary constants are expressed in Equations 1–3.

$$Z_o=\sqrt{\frac{L}{C}}\,\frac{1}{2}\sqrt{\frac{\mu}{\epsilon}}\left[\frac{(b-a)\ln b/a}{\pi(b-a)+w\ln b/a}\right] \qquad (1)$$

$$\alpha=\alpha_R+\alpha_G=\frac{R}{2Z_o}+\frac{GZ_o}{2} \qquad (2)$$

$$\alpha_R=\frac{\sqrt{\pi\rho\epsilon f}\left[\frac{1}{a}+\frac{1}{b}\right]\left[w\ln\frac{b}{a}+\pi(b-a)\right]}{(b-a)\ln\frac{b}{a}\left[w\left(\frac{1}{a}+\frac{1}{b}\right)+2\pi\right]} \qquad (3)$$

where

ρ = resistivity of conductors in ohm meters
f = frequency in Hz
μ = magnetic permeability of conductors in henrys/meter
ϵ = dielectric constant of insulation in farads/meter
$\omega=2\pi f$
Z_o = characteristic impedance
R = resistance in ohms/meter
G = conductance in siemens/meter
L = inducatance in henrys/meter
C = capacitance in farads/meter
ϵ_r = relative permittivity
α = total attenuation in nepers/meter
α_R = loss due to conductors in nepers/meter
α_G = loss due to dielectric in nepers/meter

ATTENUATION

To exhibit the attenuation characteristics as a function of dimensions, Equation (3) is normalized with respect to *b* and *a* respectively. Thus

$$\alpha_b=\frac{b\alpha_R}{\sqrt{\pi\rho\epsilon f}}=\frac{(b/a+1)[(w/b)ln(b/a)+\pi(1-a/b)]}{(1-a/b)ln(b/a)[(w/b)(b/a+1)+2\pi]} \qquad (4)$$

$$a_a=\frac{a\alpha_R}{\sqrt{\pi\rho\epsilon f}}=\frac{(1+a/b)[(w/a)ln(b/a)+\pi(b/a-1)]}{(b/a-1)ln(b/a)[(w/a)(1+a/b(+2\pi]} \qquad (5)$$

The asymptotic conditions of $w=0$ and $w=\infty$ result in

$$a_b\Big|_{w=0}=\frac{(b/a+1)}{2ln(b/a)} \qquad (6)$$

$$a_b\Big|_{w=\infty}=1/(1-ab) \qquad (7)$$

$$\alpha_a\Big|_{w=0}=\frac{(a/b+1)}{2ln(b/a)} \qquad (8)$$

$$\alpha_a\Big|_{w=\infty}=1(b/a-1) \qquad (9)$$

These formulas represent the cases of coaxial line (w=0) and infinite parallel strip line (w=∞).

In FIGS. 3 and 4,

$$b\alpha/\sqrt{f}=\alpha_b\sqrt{\pi\rho\epsilon}\ \text{and}\ a\alpha/\sqrt{f}=\alpha_a\sqrt{\pi\rho\epsilon}$$

are plotted respectively for the conditions ϵ_r = 2.28 (for polyethylene) and ρ = 1.741 by 10^{-8} ohm meters (for copper). FIG. 3 particularly demonstrates the interaction between the coaxial and the parallel lines in the intermediate dimension case. Notice that the standard optimization conditions for coaxial are exhibited. The null region broadens until the hyperbolic form dominates. This is equivalent to varying *b/a* holding *b* constant. FIG. 4, on the other hand shows a simple family of hyperbolics with no local minimal or maxima analogous to varying *b/a* holding a constant.

IMPEDANCE

The normalized equations for impedance from Equation 1 are:

$$Z_b=\frac{1}{2}\sqrt{\frac{\mu}{\epsilon}}\,\frac{(1-a/b)\ln(b/a)}{\pi(1-a/b)+(w/b)\ln(b/a)} \qquad (10)$$

and

$$Z_a=\frac{1}{2}\sqrt{\frac{\mu}{\epsilon}}\,\frac{(b/a-1)\ln(b/a)}{\pi(b/a-1)+(w/a)\ln(b/a)} \qquad (11)$$

FIGS. 5 and 6 are graphical representatives of Equations 10 and 11. As in attenuation, these represent the case where *b* and *a*, respectively, are held constant. The conditions w=0 and w=∞ lead to

$$Z_a\big|_{w=0}=Z_b\big|_{w=0}=\frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon}}\ln(b/a) \qquad (12)$$

and

$$Z_a\big|_{w=\infty}=Z_b\big|_{w=\infty}=0 \qquad (13)$$

It should be noted from FIGS. 3 and 5 that operating a circular coax in its minimum loss region

$$\left(\frac{b}{a}\approx 3.6\right)$$

fixes its impedance to approximately 50 Ω (for polyethylene). In contrast, due to the broadening of the minimum loss region for 1.0 < w/b < 1.5, a wide range of impedances can be obtained with FCC without a significant penalty in added loss.

EXACT REPLACEMENT CABLE

The nature of Equations 1 and 3 permit a flat coaxial cable to be designed to match the impedance and loss of any existing coaxial cable. Equation (3) shows that once *b*, *a*, and *w* are fixed (and ϵ, of course) α (=α_R) simply exhibits the characteristic square root of frequency shape. Thus if the slope is fixed, then the attenuation curves for FCC and a circular coax will be identical (at least for high frequencies). The characteristic impedance given in Equation (1), on the other hand, has no frequency characteristic and can be considered the infinite frequency asymptotic value.

DIMENSIONAL SENSITIVITIES

An important consideration in the evaluation of any new cable design is the penalty inherent in failure to meet strict tolerances. For the present invention, appreciable relaxation of tolerances will achieve similar objectives on attenuation deviations, while similar tolerances will achieve diminished attenuation deviations when compared to standard circular designs.

To illustrate the above, let $\bar{x}=(x_1, x_2, x_3)$ where the elements of the vector $\bar{x}$ can be identified with the parameters (*a*, *b*, *w*). Let the dimensional sensitivity coefficients be

$$k_{x_i}=\left(\frac{\partial\alpha\bar{x}}{\alpha}\right)\Big/\left(\frac{\partial x_i}{x_i}\right) \tag{14}$$

Then

$$\sum_{i=1}^{N} k_{x_i}=-1 \tag{15}$$

where $N=2$ or 3. Furthermore,

$$\lim_{\frac{x_2}{x_1}\to\infty}\sum_{i=1}^{N} k_{x_i}^2=1 \tag{16}$$

where $N = 2$ or 3. The implications of relation (16) can be seen in FIG. 7. The heavy curve represents the normal operating range for circular coaxial cables. The specific sensitivity coefficients are:

$$k_{x_1}=\left(\frac{\partial\alpha}{\alpha}\right)\Big/\left(\frac{\partial a}{a}\right)=-\frac{1}{1+a/b}-\frac{(w/b)+\pi a/b}{(w/b)\ln(b/a)+\pi(1-a/b)}+\frac{w/b}{(w/b)(1+a/b)+2\pi(a/b)}+\frac{1}{\ln(b/a)}+\frac{1}{(b/a)-1} \tag{17}$$

$$k_{x_2}=\left(\frac{\partial\alpha}{\alpha}\right)\Big/\left(\frac{\partial b}{b}\right)=-\frac{1}{b/a+1}-\frac{1}{1-a/b}-\frac{1}{\ln b/a}+\frac{w/b}{(w/b)(b/a+1)}+\frac{(w/b)+\pi}{(w/b)\ln(b/a)+\pi(1-a/b)} \tag{18}$$

$$k_{x_3}=\left(\frac{\partial\alpha}{\alpha}\right)\Big/\left(\frac{\partial w}{w}\right)=\frac{\pi(w/b)(2\ln b/a-b/a+a/b)}{[(w/b)\ln b/a+\pi(1-a/b)][(w/b)(b/a+1)+2\pi]} \tag{19}$$

From these equations, the sensitivities to other parameters such as b/a may easily be found and the sensitivities using the normalized equations α_b and α_a, equations (4) and (5) may also be found. The relationships are:

$$k\alpha_b=K_b-1 \tag{20}$$

$$k\alpha_a=K_a-1 \tag{21}$$

$$k_{b/a}=k_a k_b/(k_a-k_b) \tag{22}$$

where $k_a=k_{x_1}$ and $k_b=k_{x_2}$

To lend some additional support to FIG. 7, it may be argued that the total percent uncertainty in attenuation is given by

$$\pm\left(\frac{\Delta\alpha}{\alpha}\right)=\pm k_{x_1}\left(\frac{\Delta a}{a}\right)\pm k_{x_2}\left(\frac{\Delta b}{b}\right)\pm k_{x_3}\left(\frac{\Delta w}{w}\right) \tag{23}$$

Since the three processes are independent, we plot the power sum of the coefficients assuming that the specification percent tolerances of all three dimensions will probably be equal.

From the foregoing, it is readily seen that the advantage gained using the FCC concept depends on its use in the operating range of $b/a > 10$ and $w/b < 1.5$. This is contrasted to the usual circular case where $3 < b/a < 5$.

It is significant to note the results of dimensional tolerances on characteristic impedance. In many applications, computer cables for example, impedance uniformity is much more important than attenuation.

Applying definition (14) to Equation (1) with $Z_o(\bar{x})$ substituted for $\alpha(\bar{x})$ we obtain the following:

$$k_{x_1}=\left(\frac{\partial Z}{Z}\right)\Big/\left(\frac{\partial a}{a}\right)=-\frac{1}{b/a-1}-\frac{1}{\ln b/a}+\frac{\pi(a/b)+w/b}{\pi(1-a/b)+(w/b)\ln b/a} \tag{24}$$

$$k_{x_2}=\left(\frac{\partial Z}{Z}\right)\Big/\left(\frac{\partial b}{b}\right)=\frac{1}{1-a/b}+\frac{1}{\ln b/a}-\frac{\pi+w/b}{\pi(1-a/b)(w/b)\ln b/a} \tag{25}$$

$$k_{x_3}=\left(\frac{\partial Z}{Z}\right)\Big/\left(\frac{\partial w}{w}\right)=-\frac{1}{1+\frac{\pi(1-a/b)}{(w/b)\ln b/a}} \tag{26}$$

In this case,

$$\sum_{i=1}^{N} k_{x_i}=0$$

and

$$\lim_{\frac{x_2}{x_1}\to\infty}\sum_{i=1}^{N} k_{x_i}^2=2 \text{ for } N=2 \text{ or } 3$$

Following the line of reasoning culminating in Equation (23), FIG. 8 is a plot of the r.s.s. values of the sensitivity coefficients. For $w = 0$, only the region representing coaxial in its normal operating range of b/a values is shown. Consequently, as before, it can be seen that it is reasonable to operate FCC in regions ($b/a > 10$ and $w/b < 1.5$) where sensitivities are reduced both in attenuation and impedance.

In summary, the consequences of flattening coaxial cable in terms of attenuation, impedance and manufacturability have been demonstrated. The structure possesses a versatility owing to the range of impedances that can be obtained while the cable is operating near an optimum point. Further, cross-talk is likely to be less, in general, between two flat cables placed side by side with their inner conductors coplanar. It is seen also that manufacturing costs stand a chance of reduction because flattened coaxial cable may be made by laminating strips rather than by extrusion. Also, high frequency integrated circuitry may benefit from thin film flat cable for short runs.

It is to be understood that the embodiments described herein are merely illustrative of the principles of the invention. Various modifications may be made thereto by persons skilled in the art without departing from the spirit and scope of the invention.

We claim:

1. A coaxial cable comprising:

an outer conductor having semicylindrical side portions each having an interior surface radius of curvature b, and flat top and bottom surfaces each of width w joining said side portions;

an inner conductor having semicylindrical side portions each having an exterior surface radius of curvature a, where $b < a$, and flat top and bottom surfaces each also of width w joining said last-named side portions;

where $b/a > 10$ and $w/b < 1.5$; and

spacing means for maintaining a uniform, constant material separation between said interior and exterior surfaces.

2. A coaxial cable pursuant to claim **1**, wherein said inner conductor interior is hollow.

3. A multicoaxial communications cable comprising plural coaxial cable units constructed in accordance with claim **1**, said units being disposed with their said inner conductors lying in substantially the same plane, the edges of adjacent said units being in noncontacting relation, and a unitary outer jacket surrounding all said units.

4. A coaxial cable pursuant to claim **1**, wherein said spacing means comprises a continuous insulative layer disposed between said outer and inner conductors, said layer comprising plural longitudinal undulations extending from said outer conductor interior surface and contacting said inner conductor midway of the latter's semicylindrical side portions, and also inwardly of both said side portions on both said top and bottom surfaces of said inner conductor.

5. A coaxial cable pursuant to claim **1**, wherein said spacing means comprises a plurality of units comprising first and second legs intersecting at their lengthwise midpoints, each leg having semicircular ends and a central lengthwise slit between the ends of each said leg for mounting said inner conductor, said ends contacting, and extending normally from the edges of said inner conductor, said units being combined in end-to-end relation as a honeycomb support for said outer conductor.

6. A coaxial transmission line comprising: an inner and an outer conductor whose opposing surfaces are maintained at a uniform, constant mutual separation denoted a–b, where a = the radius of curvature of said inner conductor, and b = the radius of curvature of the inside surface of said outer conductor; said surfaces comprising first and second semicircular end portions joined by flat portions of width w, and further characterized in that $b/a > 10$ and that $w/b < 1.5$.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,671,662 Dated June 20, 1972

Inventor(s) Calvin M. Miller and Robert C. Sacks

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 3, line 33, equation 1, change "$Z_o = \sqrt{\frac{L}{C}}\frac{1}{2}$" to

--$Z_o = \sqrt{\frac{L}{C}} = \frac{1}{2}$ --.

(Please note that this change was requested in our amendment received in the Patent Office on December 22, 1971.)

Column 6, line 17, change "$\frac{x_2}{x_1} \infty$" to -- $\frac{x_2}{x_1} \rightarrow \infty$ --

Signed and sealed this 20th day of February 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
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