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MEANS AND METHOD FOR TRANSMISSION LINE COMPENSATION

Filed March 17, 1965

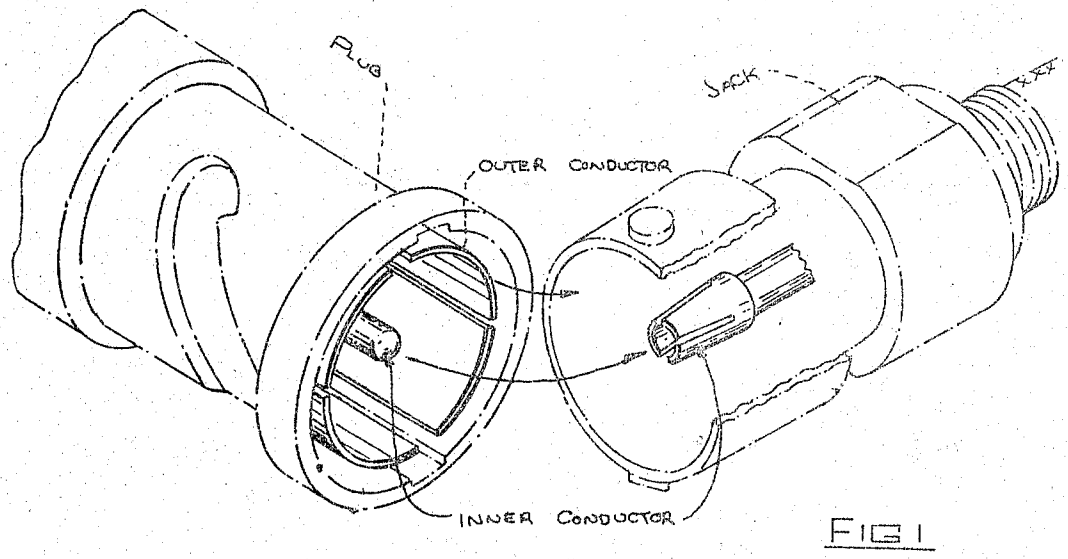


FIG 1

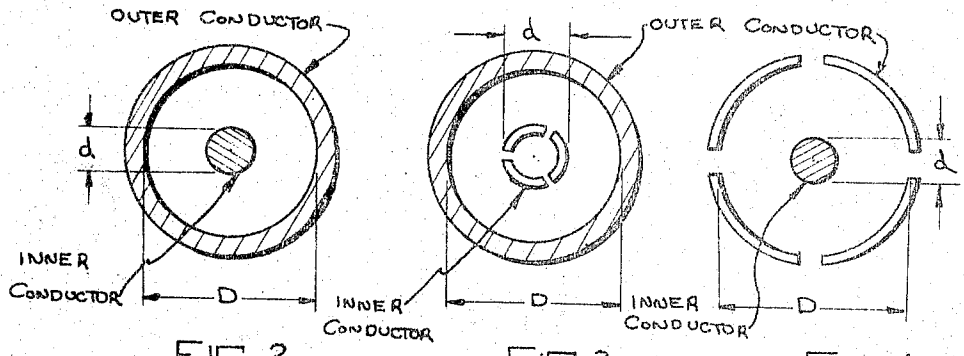


FIG 2 FIG 3 FIG 4

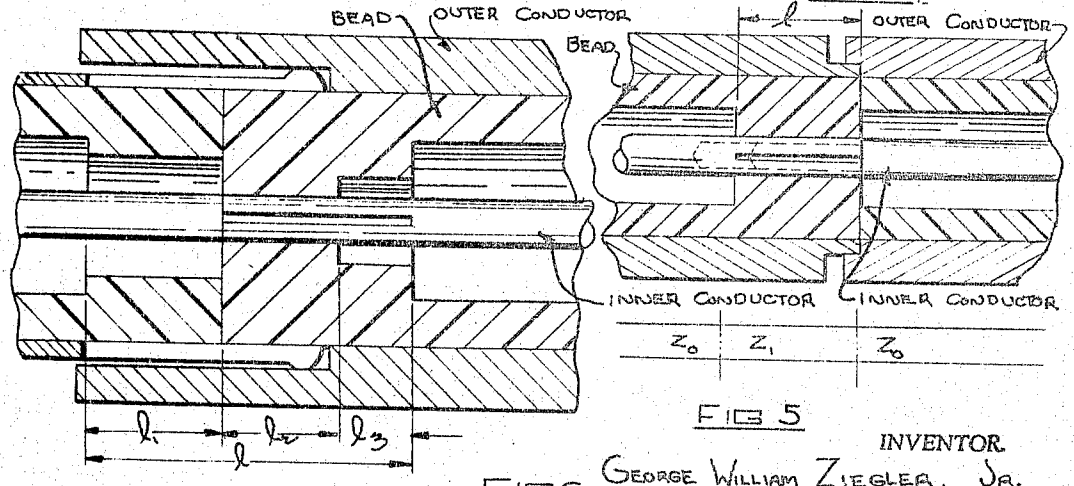


FIG 5

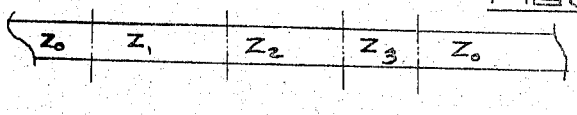


FIG 6

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MEANS AND METHOD FOR TRANSMISSION LINE COMPENSATION

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This invention relates to a method and means for providing compensation in transmission lines, particularly as represented by connectors wherein axially extending slots exist in the line inner and/or outer conductive paths.

In the typical coaxial connector there is included at least one segment wherein the outer conductor and/or the inner conductor must have resiliency to assure the establishment of a low resistance conductive path in the presence of separation and insertion procedures. This feature is most frequently carried out by forming spring fingers in one half of the connector adapted to mate with complementary portions of the other half of the connector. The presence of such structure means that slots between these spring fingers will exist extending axially for a significant length of the connector. This practice causes no problem in applications wherein the connector is utilized for shielding and is not significant in applications where signalling frequencies are relatively low; i.e., in the kilocycle or low megacycle range. As signalling frequencies rise to the kilomegacycle range all discontinuities become significant and axially extending conductor diameter differences represented by slots between spring fingers become significant to represent electrical discontinuities which cause mismatch conditions and signal reflection to an extent which is readily measurable and undesirable.

The foregoing problem has been recognized for some time and V. A. Tikhomandritskaya has commented upon it through work done as evidenced by the publication titled in English, "Coaxial Plug With Reduced Reflection Coefficient," Izmeritel'naya tekhnika (Measurement Engineering) No. 7, 1962, pp. 41–42; translation appearing in Electronic Design, vol. No. II, No. 6, Mar. 15, 1963, pp. 110–113.

The solution preferred by Tikhomandritskaya calls for calculations to determine an appropriate characteristic impedance based upon an averaging or weighting of the differences in conductor diameters caused by slotting and solves for a characteristic impedance of the segment of the connector occupied by the slotted portions as it differs from that of a homogeneous coaxial line. It is implied that following the solution for the segment characteristic impedance based upon a prorating of diameter changes, changes in the main dimensions or diameters of the conductors therein may be effected along with minimizing the slot width. The Tikhomandritskaya approach is an improvement over the prior art, which ignored discontinuities developed by slotting of the contact surfaces within a connector. Experience has shown, however, that computations carried out in accordance with the solution leave something to be desired. First of all, the suggested computation does not account for discontinuities which are present at the ends of each slot where there is a change of conductor diameter representing a discontinuity capacitance. Secondly, in most instances there is no center conductor material under a portion of the slots of the center conductor. This is due to the fact that under practical manufacturing conditions some axial space must be left for the end of the male pin as it is inserted within the female spring contacts of the center conductor contact members.

The present invention offers a different solution to the problem of discontinuities raised by the practice of slotting inner and/or outer conductors and seeks as one object to provide a method of compensating for transmission lines including connectors which include axial slots along a length of the line. It is a further object of the invention to provide a compensating dielectric insert or bead structure for transmission lines including connectors which operates to improve VSWR through sections which have slot segments disposed in the inner and/or outer conductors thereof. It is a general object of the invention to provide a method and a bead structure for connectors wherein the inner and/or outer conductive portions of necessity have spring fingers to provide a disconnect function.

The foregoing problems and objectives are met by the present invention through a method which is in part empirical and a bead structure which is in part based on such method. The method begins with an assumption that in the zone of slots in the inner and outer conductors of a connector or transmission line it is possible to devise a dielectric medium having parameters of dielectric constant and dimension to yield a characteristic impedance close to that of the line. Alternatively, it is possible to compensate for the effect of conductor slotting in terms of some other desired characteristic impedance for such segment which may be employed relative to other calculations to provide an overall compensation for the connector or line involved. The method of the invention then sets out steps to arrive at a compensating section of a desired characteristic impedance. The means of the invention is visualized as a specific bead geometry answering these requirements and inserted in lieu of existing dielectric material if such exists in a given connector or line design; or the insertion of a specific bead geometry if no bead exists and the spacing in the affected segment is air.

In the drawings:

FIGURE 1 is a perspective of male and female halves of a coaxial connector included to show the typical slotting of intermating parts of such halves which gives rise to the problem solved by the invention;

FIGURES 2, 3 and 4 are sectional views of a coaxial line included to explain the concept of the invention;

FIGURE 5 is a longitudinal schematic view of the bead structure of the invention as physically embodied to solve the problem of compensation wherein the inner conductor contact only of the connector is slotted; and

FIGURE 6 is a longitudinal schematic view showing a more complex physical arrangement to accommodate inner and outer conductor slotting in a connector.

FIGURE 1 shows jack and plug halves of a typical connector construction which is adapted to be mechanically linked together to electrically connect inner and outer conductive paths of a coaxial cable. The connector halves form a length of transmission line formed by coaxial cable and ideally should look electrically like the coaxial cable. The connector of FIGURE 1 provides, at the point of actual physical connection of the inner and outer conductors, resilient fingers which are spread or compressed by complementary conductive portions in the opposite connector half. These fingers may appear on the center conductor of one half, as in the jack half shown, and on the outer conductor portion of the other half, the plug half shown, to be separately engaged by mating portions of the opposite half. To obtain a good, low resistance connection the intermating portions must be resilient and the typical construction utilizes slotting as indicated with the metal being formed and sufficiently hard to provide spring characteristics.

FIGURE 2 shows in cross-section an idealized inner and outer conductor structure having parameters D, the inner diameter of the outer conductor and *d*, the outer diameter of the inner conductor. For the purpose of

calculating characteristic impedance Z in the segment concerned, the relationship is

$$Z=\frac{138.05}{\sqrt{K}}\log\frac{D}{d}$$

where

K is the effective dielectric constant of the material, gas (air) and/or plastic, ceramic or other suitable material between the surfaces of the conductors. When there is a change in Z in the segment the diameters D or *d* are usually adjusted in conjunction with the dielectric medium existing between the surfaces of the inner and outer conductors to arrive at a compensating bead structure to approximate a matched condition.

While some effort is being made to provide compensation wherein there are radial changes in the diameters D or *d*, no effort is presently made due to the presence of slots in either the inner conductor and/or the outer conductor. FIGURE 3 depicts the physical structure existing wherein there are slots in the inner conductor only and FIGURE 4 depicts the structure that exists wherein there are slots in the outer conductor only. There can of course be slots in both the inner and outer conductors, and such will be treated hereinafter. For the moment an examination of FIGURE 3 will reveal that computations based on *d* ignore the presence of the slots in the inner conductor and the fact that there is no center conductive material underneath the slots. This condition exists in the rearmost portion of the jack inner conductor depicted in FIGURE 1 due to the fact that the inner conductor of the plug cannot for practical purposes be made to fully seat within the inside of the jack inner conductor. By the same token calculations based upon D in FIGURE 4 ignore the presence of the slots in the outer conductor and are thus in error.

V. A. Tikhomandritskaya recognized the slot problem as previously mentioned and offered as a solution a prorating of the slots in calculations for a "proper" characteristic impedance. Finding this "proper" characteristic impedance, however does not take into consideration the lack of center conductive material in a part of the inner conductor as in FIGURE 3 and the discontinuity capacitances present at the ends of the slots on both of the slotted members in FIGURE 1. More importantly, the recommended change calls for either a change in diameter or a particular slot structure minimizing slot width.

Turning now to FIGURE 5 and the simple case represented in FIGURE 3, connector halves will be recognized to include intermating outer conductors which are not slotted and intermating inner conductors which are slotted to form pin and receptacle portions. The jack portion happens to be reversed from that shown in FIGURE 1 and the inner conductor contact of the plug portion is a receptacle formed by a bore extending as indicated by the dotted line for a length therealong; which is split to form resilient finger members and to create the slots under discussion as a problem. The jack portion includes an inner conductor pin contact adapted to be inserted within the bore and the fingers of the jack portion inner conductor contact.

Under consideration is the length of the discontinuity caused by the slots and such length is shown as *l*. For the structure shown in FIGURE 5 the sections on each side of *l* may be considered to have a characteristic impedance Z_0 and the section of length *l* may be considered to have some characteristic impedance Z_1 to form a transmission line as depicted schematically below the sectional representation. Recognizing that the existence of the axially extending slots along *l* and other discontinuities heretofore discussed are present means (assuming the dielectric material along *l* to be the same in geometry and dielectric constant as the sections adjacent *l*) Z_1 must be different from Z_0. From the basic relationship expressing characteristic impedance in terms of dielectric constant

and diameters, in FIGURE 5, one would expect Z_1 to be larger than Z_0, due to the slots and experience shows this to be so. With no compensation then Z_1 will be different from Z_0 and a mismatch will exist throughout the length *l*, adversely affecting the VSWR of the transmission line represented in FIGURE 5.

The Tikhomandritskaya approach dictates prorating the effect of slots on the changes of diameter to arrive at a compensated Z followed by changes in the diameters D and *d* in conjunction with a reduction in the slot width. The invention approach is to add bead material in the manner indicated in FIGURE 5 to change the effective dielectric constant throughout the length *l* in a direction to make Z_1 approach Z_0. This is accomplished by a step by step procedure which solves for the ratio of outer bead diameter to inner bead diameter. Once this quantity is achieved a wide variety of geometries are possible, depending upon the placement of the bead material relative to the inner and outer conductors throughout the length *l*. For example, with the bead diameter ratio being known it is readily possible to provide a bead which is disposed generally inwardly against the inner conductor portions surrounded by air, or a bead structure which resides outwardly against the inner surface of the outer conductor surrounding a portion of air and the inner conductor; in both cases extending throughout the length *l*. It is also possible to have a bead structure which is in between the surfaces of the inner and outer conductors having air disposed on either side.

In certain instances it is desirable to provide an overlapping bead structure at a joint to obtain a long voltage breakdown path. The invention is then applied by adding material to either or both portions of the overlapping bead structure which lies in the region of the slots so that the relationship of Equation 1 hereinafter given is met.

The technique for arriving at a bead geometry once the bead diameter ratio is known is described in my article titled, "Broad Band Compensation of Coaxial Connectors," Microwaves, May 1963, pp. 18–27.

The foregoing approach is based upon my discovery that an improved VSWR may be obtained by a compensated bead structure derived by finding the geometric mean value of characteristic impedances calculated for a section existing in the length *l* through different methods which respectively account for the slots and do not account for the slots. The term Z_1' represents the characteristic impedance through a section in the length *l* wherein no allowance is made in diameter change caused by the slots. K_1' is the effective dielectric constant through the section of characteristic impedance Z_1' considering the space between the inner and outer conductors as containing some dielectric medium. Z_1'' and K_1'' are similar terms taking the slots into consideration or prorating in accordance with the teachings of Tikhomandritskaya and additionally, assuming the pin contact extends fully the length of the slots. My discovery is that an adjustment providing for

$$\sqrt{Z_1'Z_1''}=Z_0$$

provides a considerably improved VSWR by a compensating section along length *l* which yields a bead structure which better compensates for the presence of slots and does not force a change of D and *d*.

Beginning then with the relationship

$$\sqrt{Z_1'Z_1''}=Z_0 \qquad (1)$$

Based on the foregoing it will be seen that

$$Z_1'=\frac{138.05}{\sqrt{K_1'}}\log\left(\frac{D}{d}\right)' \qquad (2)$$

where

$$\left(\frac{D}{d}\right)'$$

is the ratio of the inner diameter of the outer conductor and the outer diameter of the inner conductor. The characteristic impedance considering slots is

$$Z_1''=\frac{138.05}{\sqrt{K_1''}}\log\left(\frac{D}{d}\right)'' \tag{3}$$

where the ratio

$$\left(\frac{D}{d}\right)''$$

is the prorated conductor diameter ratio considering the effect of the slots.

The quantities Z_1', Z_1'', K_1', K_1'' are not solved for directly as their solution will not yield the dimensions for the bead structure, which is of course the object of the manipulation of the method of the invention. Rather, forming the relationship

$$Z_1'Z_1''=Z_0^2=\frac{(138.05)^2}{\sqrt{K_1'K_1''}}\left[\log\left(\frac{D}{d}\right)'\right]\left[\log\left(\frac{D}{d}\right)''\right] \tag{4}$$

we solve for the term $K_1'K_1''$ which is

$$K_1'K_1''=\left\{\frac{(138.05)^2\left[\log\left(\frac{D}{d}\right)'\right]\left[\log\left(\frac{D}{d}\right)''\right]}{Z_0^2}\right\}^2 \tag{5}$$

Now, we have the term $K_1'K_1''$ expressed and we know the values of

$$\left(\frac{D}{d}\right)' \text{ and } \left(\frac{D}{d}\right)''$$

and we know what the characteristic impedance of the line Z_0 is.

This expression, however, still includes the diameter values for the conductors throughout the length and not the bead structure diameters. But

$$K_1'=K_{\text{effective}}=\frac{K_p\log\left(\frac{D}{d}\right)'}{K_p\log\left(\frac{D}{d}\right)'-(K_p-1)\log\frac{D'}{d'}} \tag{6}$$

where K_p is equal to the dielectric constant of the plastic bead and where the ratio D'/d' is the ratio of the bead outer diameter to the bead inner diameter, and

$$K_1''=K_{\text{effective}}=\frac{K_p\log\left(\frac{D}{d}\right)''}{K_p\log\left(\frac{D}{d}\right)''-(K_p-1)\log\frac{D'}{d'}} \tag{7}$$

Now, from Equation 5 we know what the quantity $K_1'K_1''$ is in other terms including Z_0 which are known. We can develop the relationship

$$K_1'K_1''=\frac{K_p^2\log\left(\frac{D}{d}\right)'\log\left(\frac{D}{d}\right)''}{\left[K_p\log\left(\frac{D}{d}\right)'-(K_p-1)\log\frac{D'}{d'}\right]\left[K_p\log\left(\frac{D}{d}\right)''-(K_p-1)\log\frac{D'}{d'}\right]} \tag{8}$$

and equate the $K_1'K_1''$ term of Equations 5 and 8. We can then solve this quadratic for the term $\log D'/d'$. Once the diameter ratio D'/d' is obtained we can then resort to a variety of the geometries which will be extended along the length l and provide a Z_1 approaching Z_0.

In an actual example wherein the outer conductor diameter was 0.2660 and the inner conductor diameter was 0.0830, in inches, and both conductors were slotted such that their diameters when prorated for total subtended slot angle to 360° are respectively, 0.2741 and 0.0764, in inches, the bead ratio D'/d' equal to 3.09005 for a particular bead material having a bulk dielectric constant of $K_p=2.328+0.005$ at 1300 mc. when $Z_0=50.00$ ohms. A large number of solutions exist for the particular bead structure based on this ratio generally limited only by the space between the conductors and its efficiency in a given conductor design.

In FIGURE 6 a more complex connector problem is shown wherein slots exist in the outer conductor and in the inner conductor and there is some overlap of the slotted portions with single slot discontinuities at either end attributable to the inner and outer conductors. Looking at this problem schematically we see a transmission line having characteristic impedances Z_0 at either end separated by three distinct sections of characteristic impedances Z_1, Z_2 and Z_3, which together yield a length l representing the length of the offending section. In this problem we see that the slotting of the outer conductor up to the point where it overlaps with the slotting of the inner conductor develops a discontinuity of the length l_1. The overlap length develops a discontinuity of length l_2 and the plotting of the inner conductor develops a length l_3. This problem can be treated in the above manner by handling the lengths l_1, l_2 and l_3 separately to provide compensation to Z_0. Thus, for the length l_1 we begin with the relationship

$$\sqrt{Z_1'Z_1''}=Z_0$$

and for the length l_2 we utilize the relationship

$$\sqrt{Z_2'Z_2''}=Z_0$$

and for the length l_3 we utilize the relationship

$$\sqrt{Z_3'Z_3''}=Z_0$$

When these values are calculated in a manner to yield the bead diameter ratio a bead structure extending along l may be developed which may generally appear as shown in FIGURE 6.

The invention method and means having been described to distinctly point out how to practice a preferred mode thereof, I now define the invention.

What is claimed is:

1. In a transmission line of characteristic impedance Z_0, a segment having axially extending slots therealong tending to increase the segment characteristic impedance, a compensating bead structure positioned in said segment and of a thickness and dielectric constant so that

$$Z'Z''=Z_0^2$$

where Z' is the characteristic impedance of the segment computed from the diameters of the segment conductors as if not slotted and Z'' is the characteristic impedance of the segment computed from the diameters of the segment conductors by prorating the slots.

2. The line of claim **1** where said segment is a connector inserted in said transmission line and said slots are formed in connector mating portions.

3. The line of claim **2** wherein said slots are formed in the connector outer mating portions.

4. The line of claim **2** wherein said slots are formed in the connector inner mating portions.

5. The line of claim **2** wherein said slots are formed in the connector outer and inner mating portions.

6. The line of claim **5** wherein the slots of the outer and inner mating portions only partially overlap to create zones of different Z' and Z'' values and dielectric constant for each zone such that $Z'Z''=Z_0^2$ for each zone.

7. In a connector adapted to be inserted in a line of characteristic impedance Z_0, said connector having intermating conductive portions which contain axial slots, a dielectric bead structure inserted in the region of said slots to electrically compensate for the presence thereof, said bead structure having an effective dielectric constant so that $Z'Z''=Z_0^2$ where Z' is the characteristic impedance of the segment of the connector containing said slots computed from the diameters of the inner and outer conduc-

tors of the connector and Z'' is the characteristic impedance of the segment of the connector containing said slots computed from the diameters of the inner and outer conductors prorated to account for the effect of said slots.

8. In a connector adapted to be inserted in a line of characteristic impedance Z_0 the connector having intermating conductive portions which contain axial slots to provide resiliency, an overlapping dielectric bead structure extending into the region of said slots to provide a long voltage breakdown path, an additional bead structure added to portions of the overlapping bead structure in the region of said slots to electrically compensate for the presence of said slots, the resultant bead structure having an effective dielectric constant so that $Z'Z''=Z_0^2$ where Z' is the characteristic impedance of the segment of the connector containing said slots computed from the diameters of the inner and outer conductors of the connector and Z'' is the characteristic impedance of the segment of the connector containing said slots computed from the diameters of the inner and outer conductors prorated to account for the effect of said slots.

9. In a transmission line having a characteristic impedance Z_0, a segment adapted to be inserted therein and matched to said line, said segment having axial slots extending along portions of the segment conductors such that the non-prorated conductor diameter ratio is

$$\left(\frac{D'}{d}\right)$$

and the prorated conductor diameters ratio is

$$\left(\frac{D''}{d}\right)$$

a compensating bead structure in said segment having a

dielectric constant K_p and wall thickness to provide a bead diameter ratio D'/d' whereby

$$\left\{\frac{(138.05)^2\left[\log\left(\frac{D}{d}\right)'\right]\left[\log\left(\frac{D}{d}\right)''\right]}{Z_0^2}\right\}^2 = \frac{K_p^2\left[\log\left(\frac{D}{d}\right)'\right]\left[\log\left(\frac{D}{d}\right)''\right]}{\left[K_p\log\left(\frac{D}{d}\right)'-(K_p-1)\log\frac{D'}{d'}\right]\left[K_p\log\left(\frac{D}{d}\right)''-(K_p-1)\log\frac{D'}{d'}\right]}$$

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