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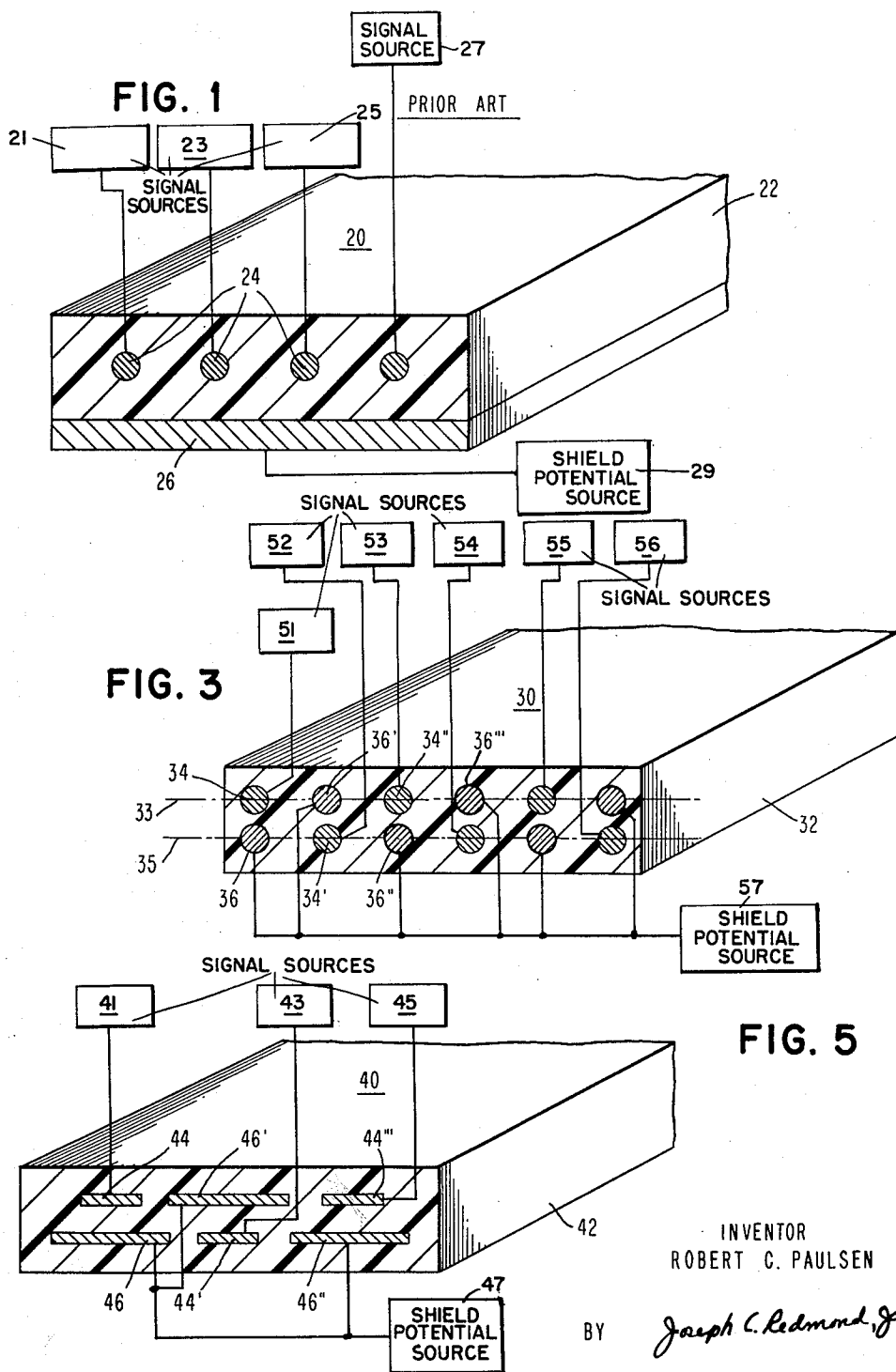
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3,179,904

FLEXIBLE MULTICONDUCTOR TRANSMISSION LINE UTILIZING  
ALTERNATE CONDUCTORS AS CROSSTALK SHIELDS

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2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 2

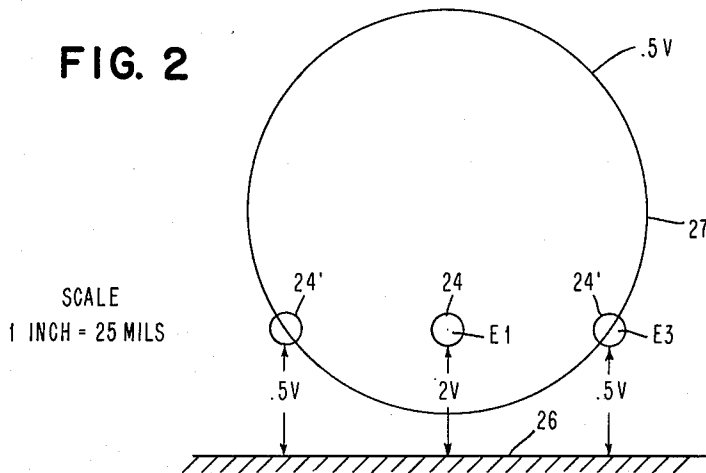
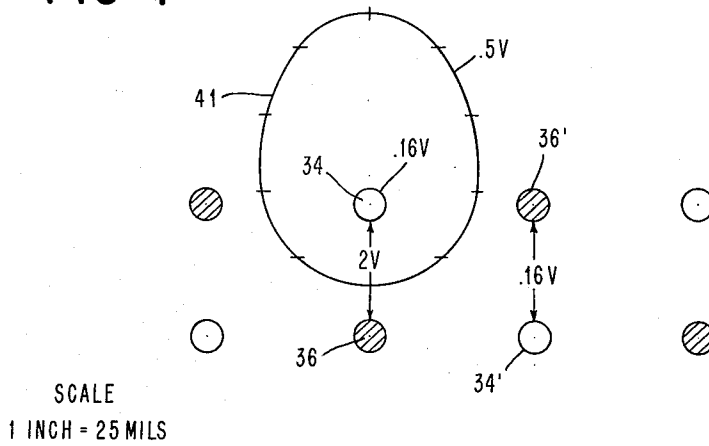


FIG 4



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## FLEXIBLE MULTICONDUCTOR TRANSMISSION LINE UTILIZING ALTERNATE CONDUCTORS AS CROSSTALK SHIELDS

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This invention relates to transmission lines, and more particularly, to flexible, multiple, conductor transmission lines suitable for manufacture in a continuous process.

As microminiaturization reduces the size of data processing apparatus, conventional single wire, twisted pair and coaxial cables become obsolete for interconnecting the various units in the apparatus. Such interconnecting lines are often too stiff and bulky and lack the flexibility required for bending within the small spaces of microminiaturized units. Tape cables, which are flat and flexible, lend themselves to microminiaturized data processing apparatus. Tape cables require less space as well as present a neater appearance than prior interconnecting elements.

Flexibility and crosstalk present problems to tape cables as the characteristic impedance requirements of the cables increase. Conventionally, an increase in characteristic impedance requirements of transmission lines results in a corresponding increase in the thickness of the cable dielectric with a resultant decrease in cable flexibility. Many times, it is desirable to fold tape cables to change direction. In certain instances, the folding brings the signal conductors in close proximity to one another with a resultant increase in crosstalk. Also, the folding often breaks or interrupts the ground conductors of such cables with a resultant increase in cable attenuation, characteristic impedance as well as crosstalk. It is desirable, therefore, to improve tape cables so that flexibility, crosstalk and attenuation problems are substantially eliminated thereby exploiting the full potential of such components in microminiaturized data processing apparatus.

A general object of the invention is an improved flexible, multiple, conductor transmission line that may be readily folded with substantially reduced cable attenuation and crosstalk difficulties.

One object is a barrier shielded transmission line.

Another object is an extremely thin tape cable having a characteristic impedance that approaches the order of 100 ohms, the impedance being substantially constant throughout the length of the cable.

Still another object is a tape cable having good limpness and sufficient shielding to substantially eliminate crosstalk.

These and other objects are accomplished in accordance with the present invention, one illustrative embodiment of which comprises an insulating member having a preselected dielectric constant, a plurality of signal conductors having a diameter  $d_1$ , and a plurality of ground conductors having a diameter  $d_2$ , where  $d_1 \leq d_2$ , the signal and ground conductors being juxtaposed in the insulating member in a series of superimposed conductive planes. Alternate conductive planes are offset the same direction and extent with respect to the superimposed planes so that each signal conductor is surrounded by at least three ground conductors. The diameters of the ground and signal conductors and dielectric constant of the insulating material cooperate to permit a thin tape cable that has little or no crosstalk when electrical signals are supplied to the signal conductors. The cable attenuation is substantially constant regardless of the number of folds made in the cable since the ground conductors have a strength which will not fracture when folded upon themselves.

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One feature of the invention is a plurality of first and second conductive members positioned in the dielectric, the configuration of the conductive members being such that each first conductive member is surrounded by at least three second conductive members.

Another feature is a plurality of superimposed conductor planes whereby each conductor plane has alternate conductive members of different diameters, corresponding conductors in each plane being of different diameter.

Another feature is a tape cable that surrounds each signal path with at least three ground conductors to nullify crosstalk among signal paths.

Another feature is a tape cable having a plurality of superimposed conductor planes wherein each plane comprises a plurality of ground and signal conductors in juxtaposed relation, the cable having a characteristic impedance given by an empirical relation:

$$Z_0 = \frac{100}{\sqrt{\epsilon_r}} \ln \frac{3D_v D_h}{(2D_v + D_h) \sqrt{d_1 d_2}}$$

where  $\epsilon_r$  = the dielectric constant of the cable;  $D_h$  = the horizontal spacing between conductors;  $D_v$  = the vertical spacing between cable conductor planes;  $d_1$  = the diameter of signal conductors and  $d_2$  = the diameter of ground conductors.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiment of the invention, as illustrated in the accompanying drawings.

FIGURE 1 is an axial view of a tape cable disclosed in the prior art.

FIGURE 2 is an equipotential plot of the field intensity of one conductor in the cable of FIGURE 1.

FIGURE 3 is an axial view of a flexible, multiple conductor transmission line employing the principles of the present invention.

FIGURE 4 is an equipotential plot of the field intensity of one conductor in the cable of FIGURE 3.

FIGURE 5 is an axial view of another cable employing the principles of the present invention.

Referring to FIGURE 1, a tape cable 20 presently available on the commercial market includes an insulating member 22, typically vinyl or Teflon plastic, having embedded therein a plurality of conductors 24 which serve as signal paths for individual signals received from signal sources 21, 23, 25 and 27 respectively. Secured to one side of the cable is a metallic member 26 which is connected to shield potential source 27 and serves as a ground return conductor for the signal paths. Customarily, the tape cable 20 is referred to as a ground plane cable. For a signal conductor spacing of 40 mils, a dielectric constant of 2, a characteristic impedance of the order of 100 ohms, an attenuation of .15 db/lineal foot at 30 megacycles, a maximum D.C. resistance of .25 ohm/lineal foot for signal conductors, the thickness of the prior art cable is of the order of 30 to 50 mils. For microminiaturized data processing units, it has been determined that tape cables should withstand a one time sharp creased flat fold on themselves without any fracture or decrease in insulation resistance. Laboratory experience has indicated that metal-clad ground planes for the cable indicated in FIGURE 1 will fracture when folded in the manner described. As a result, the attenuation of the cable is increased with the metallic shield of such cables fractured. Crosstalk between the folded conductors also increases to a prohibitive level.

Referring to FIGURE 2 an equipotential plot of the field intensity for a conductor 24 indicates the coupling between adjacent conductors. The plot was made by constructing an analog model of the prior art cable scaled to the aforementioned dimensions and characteristic imped-

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ance in accordance with the analog field plot technique described in "Electrical Engineering," September 1961, page 699. For purposes of the plot a 2 volt D.C. level was applied between the conductor 24 and the ground plane 26. A conventional vacuum tube voltmeter was employed to establish a .5 volt equipotential line 27. The voltage to ground at conductor 24' was .5 volt and the ratio of the voltages to ground of conductors 24 and 24' was 1/4. The 1/4 ratio which represents the magnitude of the signal level coupled from conductor 24 to conductor 24' will be employed hereinafter as a basis for comparison with the present invention.

FIGURE 3 discloses a tape cable 30 employing the principles of the present invention. The cable 30, which will be referred to hereinafter, is a barrier shielded cable. The present invention, as will appear hereinafter, overcomes the limitations of prohibitive crosstalk and attenuation, previously enumerated, for the grounded plane cable 20 shown in FIGURE 1.

The cable 30 includes an insulating member 32, typically Teflon or the like, signal conductors 34, 34', 34'' . . . of diameter  $d_1$  which are connected respectively to signal sources 51, 52, 53, 54, 55 and 56 and ground or shielding conductors 36, 36', 36'' . . . of diameter  $d_2$  which are connected to shield potential source 57 where preferably but not exclusively  $d_1 \leq d_2$ . It should be noted that although six signal conductors are indicated, the cable is not necessarily limited to such a number but may have any quantity depending upon the limitations of the cable fabricating apparatus. The signal and ground or shielding conductors are arranged in the insulating member 32 in conductor planes 33 and 35. Each conductor plane has alternate signal and ground conductors in juxtaposed relation. Successive conductor planes are arranged in offset relations, that is, a ground conductor is associated with each pair of superimposed conductors in the conductor planes. Thus, considering any set of superimposed conductors in the conductor planes, it will be noted that a ground conductor is included in each set of superimposed conductors. Additionally, adjacent sets of superimposed conductors are in inverted relation. Thus, in one set of superimposed conductors the signal conductor will be above the ground conductor whereas in the next or adjacent set of conductors, the ground conductor is above the signal conductors. The superimposed conductor sets are repeated in this manner along the width of the conductor. The result of this conductor arrangement is to surround each signal conductor with at least three ground conductors. For example, the signal conductor 34' is surrounded by ground conductors 36, 36' and 36''. Signal conductors 34'' are surrounded by ground conductors 36', 36'' and 36'''. This grounding configuration provides a shielding effect which reduces the crosstalk between adjacent diagonally disposed signal conductors (34 and 34') as well as the crosstalk between signal conductors (34 and 34'') disposed in the same plane.

For any characteristic impedance  $Z_0$ , the particular dimensions of the signal and ground conductor geometry necessary to obtain a tape cable with reduced coupling is given by the following empirical relation developed from the analog field plot for the cable of FIGURE 3:

$$Z_0 = \frac{100}{\sqrt{\epsilon_r}} \ln \frac{3D_v D_h}{(2D_v + D_h) \sqrt{d_1 d_2}}$$

where:

$Z_0$ =characteristic impedance of the line  
 $\epsilon_r$ =dielectric constant of the insulation  
 $D_h$ =horizontal spacing between conductors in a plane  
 $D_v$ =vertical spacing between conductor planes  
 $d_1$ =diameter of the signal conductors  
 $d_2$ =diameter of the ground conductors.

Referring to FIGURE 4, an equipotential plot of the field intensity for a conductor 34 of the cable shown in FIGURE 3 indicates the coupling between adjacent con-

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ductors. The plot was constructed by the analog field plot procedure previously described. The physical characteristics of the line examined, that is, thickness, dielectric, conductor spacing, were the same as those for the grounded plane cable of FIGURE 1. A comparison of the field plots for conductors in the cables of FIGURES 1 and 3, as a result, indicates the relative electromagnetic radiation and line coupling of the lines. The radiation and coupling of a line, as is well-known in the art, are proportional to the attenuation and crosstalk, respectively, of the lines.

To facilitate comparison between the field plots, the .5 volt to ground equipotential line measurement is indicated in FIGURE 4. It is apparent that the .5 volt equipotential circle 41 of FIGURE 4 is of less diameter than that for FIGURE 2. Hence, the crosstalk and attenuation of the cable of FIGURE 3 are less than that for FIGURE 1. Actually, the voltage to ground measured at conductor 34' was of the order of 160 millivolts. Thus, the coupling or crosstalk ratio between diagonally disposed signal conductors 34, 34' of FIGURE 3 is approximately 1/12.5 which is more than a one-third reduction in coupled voltage for the cable of FIGURE 3 than that of FIGURE 1.

The attenuation associated with the cable of FIGURE 3 is also reduced with respect to that of FIGURE 1. Since attenuation is proportional to the electromagnetic radiation extending from the cable, it is believed evident from FIGURES 2 and 4 that the radiation extends further from FIGURE 1 than that for FIGURE 3. Hence, the attenuation of the latter is less than that for the former. Actual decibel measurements on the cables indicated a .17 db/ft. loss for the cable of FIGURE 1 whereas the cable of FIGURE 3 had a .10 db/ft. loss.

Summarizing, Table I below provides comparative data of cables of substantially identical physical dimensions and electrical characteristics for the geometrical configurations indicated in FIGURES 1 and 3:

Table I

| Parameters                                     | Figure 1<br>(Ground<br>Plane) | Figure 2<br>(Barrier<br>Shield) |
|------------------------------------------------|-------------------------------|---------------------------------|
| (a) Characteristic Impedance.....ohms...       | 95                            | 95                              |
| (b) Signal Conductor Resistance.....ohms/ft... | .2                            | .2                              |
| (c) Crosstalk Ratio.....                       | 1/4                           | 1/12.5                          |
| (d) Attenuation (30 mc.).....db/ft...          | .17                           | .10                             |

Electrically, the barrier shielded cable has a crosstalk factor heretofore not possible in tape cables of conductor separations of the order of tens of mils. The crosstalk factor is defined as the ratio in decibels of the signal level coupled into one conductor from an adjacent conductor. Employing the well-known relation

$$\text{db} = \log \frac{V_1}{V_2}$$

where  $V_2$  is the voltage appearing on one conductor and  $V_1$  the coupled voltage appearing on an adjacent conductor, the crosstalk factor for the barrier shielded cable is -22 db whereas that for the grounded plane conductor is -12 db. It is believed evident that a signal coupling of -12 db on a transmission line would sufficiently alter the signal on a line to a point that it would not be useful in information processing. Thus, tape cables of the type shown in FIGURE 1 are not practicable in microminaturized data processing apparatus. Laboratory experience indicates, however, that crosstalk factors of -22 db are well within the signal tolerances established for such apparatus.

Mechanically, the tape cable shown in FIGURE 3 has improved flexibility due to the ground plane being a series of individual conductors which may be readily folded without fracture of the conductors. Further, for given physical dimensions, the present invention has indicated that improved electrical characteristics are realized over

the prior art cable. Conversely, for identical electrical characteristics, the present invention provides reduced physical dimensions, i.e., thickness, spacing of conductors and wire size with respect to the prior art because of the improved shielding and attenuation properties of the barrier shielded cable. Tape cables employing the principles of present invention are obtainable with  $\frac{3}{4}$  to  $\frac{1}{2}$  thickness of the prior art cable. Correspondingly, tape cables of the present invention are obtainable with  $\frac{3}{4}$  to  $\frac{1}{2}$  the width of the prior art cables. The reduced thickness and width of the present invention provide improved flexibility for interconnecting microminiaturized units.

Thus, in summary, the present invention has provided a new and improved tape cable which has the required electrical and mechanical characteristics necessary for interconnecting microminiaturized units in a data processing system.

Another embodiment of the present invention, shown in FIGURE 5, is a tape cable 40. Included in the cable 40 is an insulating member 42, typically Teflon or the like, having signal conductors 44, 44', 44'' . . . which are connected respectively to signal sources 41, 43 and 45 and ground conductors 46, 46', 46'' . . . which are connected to shield potential source 47, in juxtaposed relation in two or more superimposed conductor planes. The cable conductors of FIGURE 5 are flat, however, as compared to the cylindrical conductors of FIGURE 3. Actually, in both embodiments, the conductors may be of any configuration. Alternate conductor planes are arranged in the manner described in connection with FIGURE 3, i.e., each set of superimposed conductors includes a ground conductor and a signal conductor. Alternate sets of superimposed conductors are in inverted order. The tape cable of FIGURE 5 includes an additional feature which further improves the crosstalk factor and attenuation of the cable. Preparing equipotential plots of the field intensities of the cable conductors, in the manner previously described, produces coupling ratios of the order of 1/17. When converted, the 1/17 coupling ratio corresponds to a crosstalk factor of -25 db with little or no sacrifice in attenuation. Thus, the cable of FIGURE 5 has further improved performance over that of FIGURE 1.

The particular dimensions of the signal and ground conductor geometry for the tape cable 40 is given by the following empirical relation ( $\pm 10\%$ ):

$$Z_0 = \frac{100}{\sqrt{\epsilon_r}} \ln \frac{3D_v D_h}{(2D_v + D_h) d_0}$$

where signal and ground conductor thickness < signal and ground conductor width; signal conductor thickness = ground conductor thickness;  $D_h$  = center-to-center spacing of conductors in the same plane;  $D_v$  = spacing between horizontal axes for the adjacent conductor planes;  $\epsilon_r$  = dielectric constant and

$$d_0 = .67W_s \left( .8 + \frac{T}{W_s} \right)$$

where  $W_s$  = the width of the signal conductors and  $T$  = the thickness of the signal conductor and  $W_g \leq W_s$  where  $W_g$  is the width of the ground conductor.

The present invention depends, in large part, upon the geometrical relation of the signal and ground conductors in an insulating member. The ground and signal conductors may be embedded in an insulating medium or fabricated by well-known printed circuits or like techniques. One procedure for fabricating the cable is to superimpose on a sheet of Teflon or like plastic, a plurality of etched or wire conductors. Thereafter, a second sheet of plastic can be superimposed on the etched or wire conductors followed by another plurality of conductors. A final sheet of plastic can be superimposed on the top conductor and the entire assembly laminated together. The dimensions of the plastic sheets, conductors, dielectric constant should be selected in accordance with the formulae previously indicated for the cable desired. Fabricating such

conductors in a continuous process is well-known in the art as evidenced by U.S. Patent No. 2,849,298, issued on August 26, 1958.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A flexible, multiple, conductor transmission line comprising

an insulating member of suitable dielectric constant at least two conductor planes included in the insulating member,

each conductor plane including a plurality of conductors of diameters  $d_1$  and  $d_2$ , respectively, alternate conductors in a plane being adapted as ground conductors,

the remaining conductors in a plane being adapted as signal conductors, the signal conductors having a diameter  $d_1$  and the ground conductors having a diameter  $d_2$  where  $d_1 \leq d_2$ ,

corresponding conductor positions in each plane comprising a ground conductor and a signal conductor whereby each signal conductor is surrounded by at least three ground conductors and, for transmission lines having a characteristic impedance of the order of 100 ohms, a spacing between the conductor planes and adjacent conductors on a conductor plane to provide a crosstalk ratio of 1/12.5 between a signal level coupled by the signal conductor to the next adjacent signal conductor and a signal level on the signal conductor.

2. A flexible, multiple, conductor transmission line comprising

an insulating member of suitable dielectric constant at least two conductor planes included in the insulating member,

each conductor plane including a plurality of ground and signal conductors,

alternate conductors being ground conductors, the remaining conductors being signal conductors,

corresponding conductors in each conductor plane comprising a signal conductor and a ground conductor, and for transmission lines having a characteristic impedance of the order of 100 ohms, a spacing between conductor planes and adjacent conductors in a plane given by:

$$Z_0 = \frac{100}{\sqrt{\epsilon_r}} \ln \frac{3D_v D_h}{(3D_v + D_h) \sqrt{d_1 d_2}}$$

where  $\epsilon_r$  = the dielectric constant of the insulating member;  $D_h$  = the horizontal spacing between the conductors in a conductor plane;  $D_v$  = the vertical spacing between conductor planes;  $d_1$  = the diameter of signal conductors;  $d_2$  = the diameter of ground conductors and  $Z_0$  = the characteristic of the transmission line.

3. A flexible, multiple, conductor transmission line comprising

an insulating member of suitable dielectric constant, at least two conductor planes included in the insulating member,

each conductor plane including a plurality of flat conductors in juxtaposed relation,

alternate flat conductors in each plane defined as ground conductors,

the remaining flat conductors in the conductor planes defined as signal conductors,

corresponding conductor positions in each plane comprising a ground conductor and a signal conductor, the ground conductor in each conductor position overlapping the ground conductor in the adjacent conductor position.

4. A flexible, multiple, conductor transmission line comprising:  
 an insulating member of suitable dielectric constant, at least two conductor planes included in the insulating member,  
 each conductor plane including a plurality of shielding and signal conductors,  
 a plurality of signal sources connected to said signal conductors, and  
 a shielding potential source connected to said shielding conductors,  
 said signal and shielding conductors being arranged in the respective conductor planes such that each conductor adjacent to a signal conductor in its respective conductor plane and in a direction normal to that plane is a shielding conductor.
5. A flexible, multiple, conductor transmission line comprising:  
 an insulating member of suitable dielectric constant, at least two superimposed conductor planes included in the insulating member, and  
 a plurality of conductors in juxtaposed relation included in each conductor plane,  
 alternate conductors in each plane being adapted as ground conductors,  
 the remaining conductors in each plane being adapted as signal conductors,  
 alternate conductor planes being horizontally offset with respect to its superimposed conductor plane whereby corresponding conductors in each plane include a ground conductor and a signal conductor,  
 a plurality of electric signal sources connected to said signal conductors, and  
 electric potential sources connected to each of said ground conductors.
6. A flexible, multiple, conductor transmission line comprising:  
 an insulating member having a lateral and longitudinal axis and being of suitable dielectric constant,  
 a plurality of signal conductors included in the member and extending parallel to said longitudinal axis, and  
 a like plurality of ground conductors included in the member and extending parallel to said longitudinal axis,  
 selected ground and signal conductors comprising pairs

- of conductors with alternate pairs having the ground conductor normally superimposed above the signal conductor, said pairs being spaced along the lateral axis of the member,  
 the remaining pairs of conductors spaced along the lateral axis having the signal conductor superimposed above the ground conductor,  
 a plurality of electric signal sources connected to said signal conductors, and  
 electric potential sources connected to each of said ground conductors.
7. A flexible, multiple, conductor transmission line comprising:  
 an insulating member having a lateral axis and a longitudinal axis and being of suitable dielectric constant, and  
 at least two conductor planes included in the insulating member in parallel relation with respect to the longitudinal axis of the member,  
 each conductor plane including a plurality of ground and signal conductors in spaced relation along the lateral axis of the member,  
 alternate conductors in each plane being adapted as ground conductors,  
 the remaining conductors in the conductor planes being adapted as signal conductors,  
 corresponding conductor positions in each conductor plane comprising a signal conductor and a ground conductor whereby each signal conductor is surrounded by a plurality of ground conductors,  
 a plurality of electric signal sources connected to said signal conductors, and  
 electric potential sources connected to each of said ground conductors.

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