

[54] **CONDUCTOR WITH INSULATIVE LAYER
COMPRISING WOOD PULP AND
POLYOLEFIN FIBERS**

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[63] Continuation-in-part of Ser. No. 359,743, May 14,
1973, abandoned, which is a continuation of Ser. No.
921,427, Nov. 24, 1970, abandoned.

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174/113 R; 174/120 R

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[58] **Field of Search**..... **162/138, 157 R; 174/110 P,**
174/110 R, 110 PM, 113 R, 120 R

[56]

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[57]

ABSTRACT

A conductor insulated with a composition of wood
pulp and polypropylene or polyethylene fibers is found
to exhibit enhanced properties. As compared to wood
pulp alone, dissipation factor and dielectric constant
are substantially reduced in magnitude and variability,
particularly at high frequencies.

4 Claims, 7 Drawing Figures



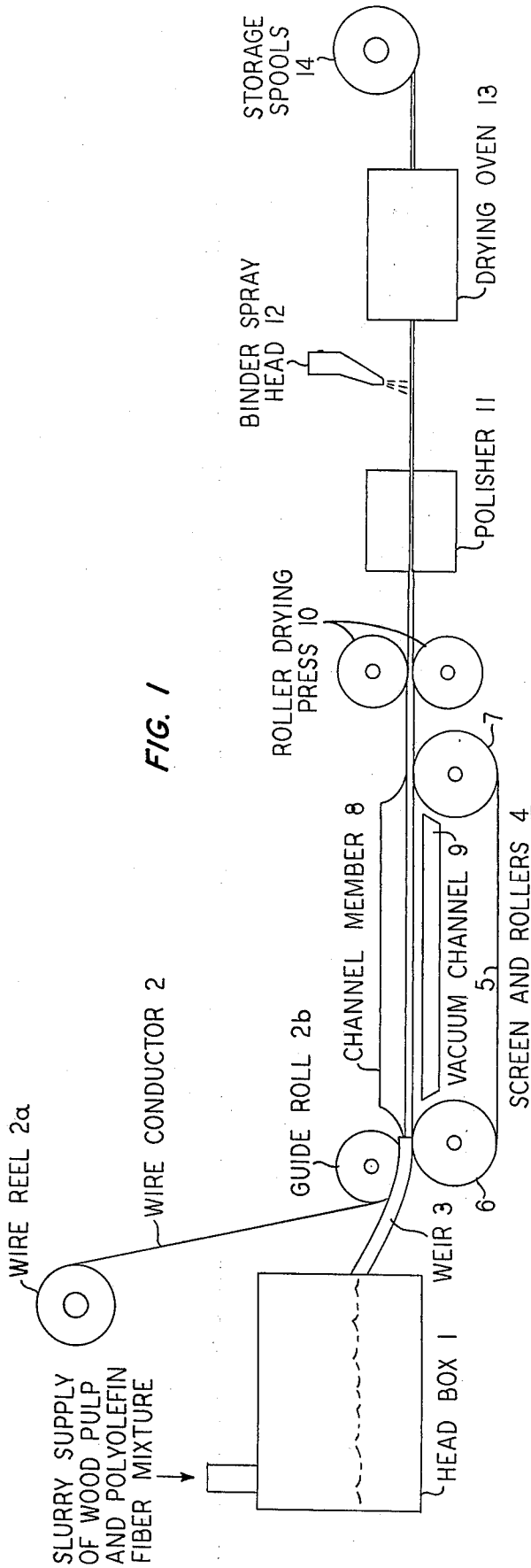


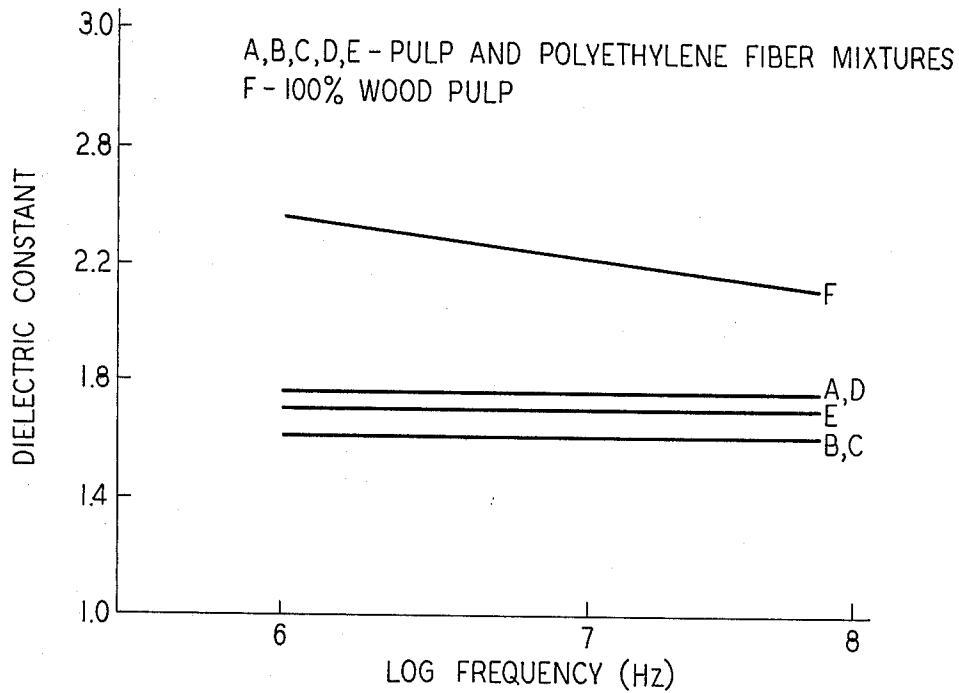
FIG. 2



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FIG. 3

WOOD PULP + POLYETHYLENE FIBERS

**FIG. 4**

WOOD PULP + POLYETHYLENE FIBERS

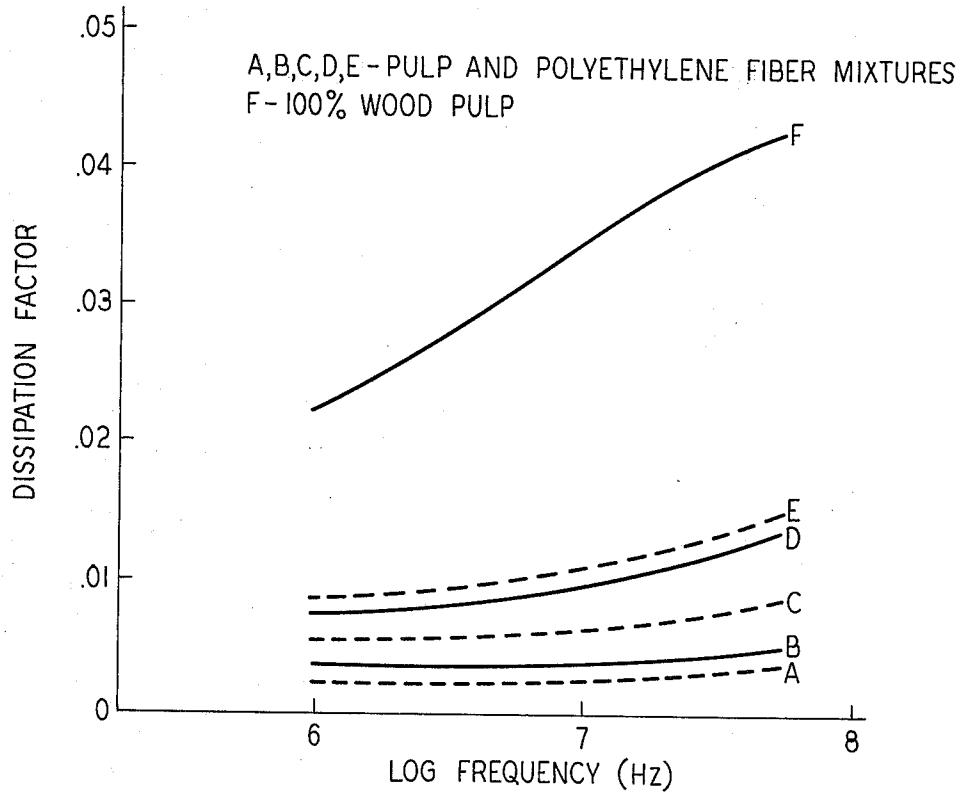


FIG. 5

WOOD PULP + POLYETHYLENE FIBERS + BRANCHED POLYETHYLENE BINDER

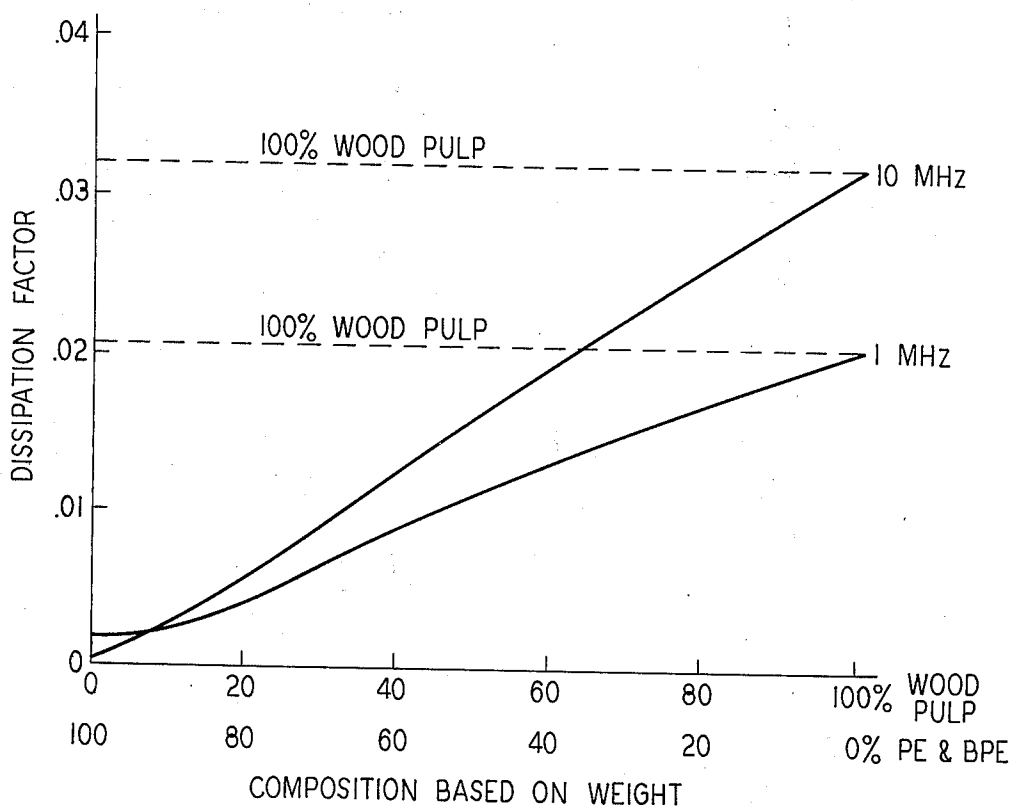
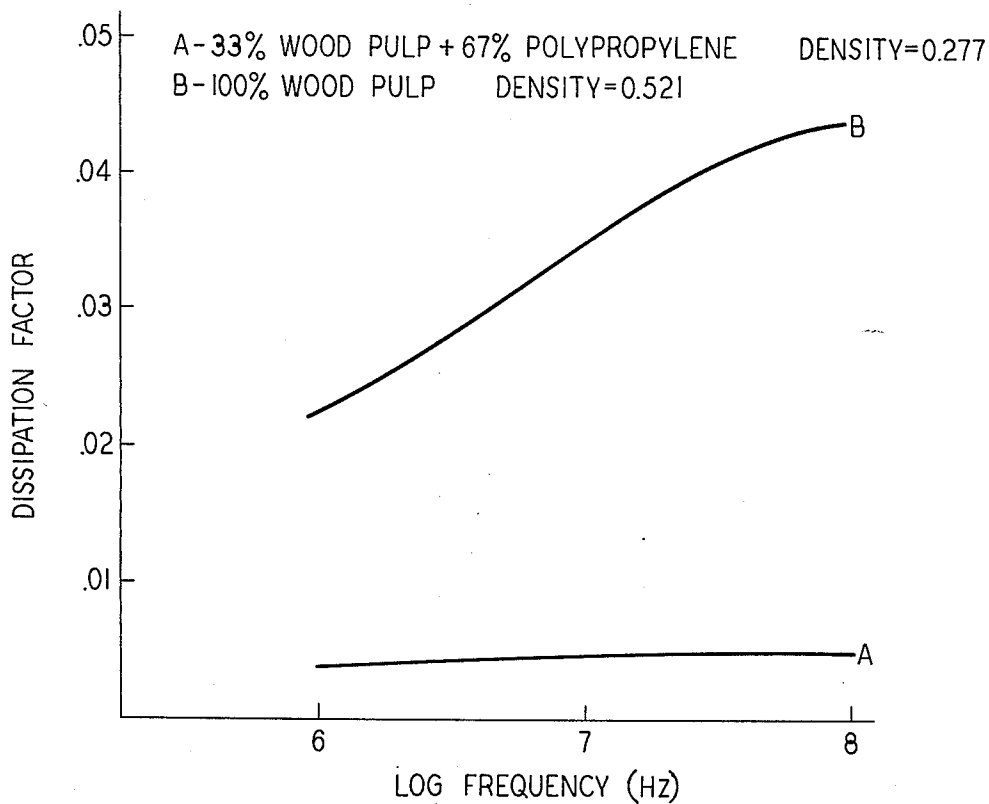
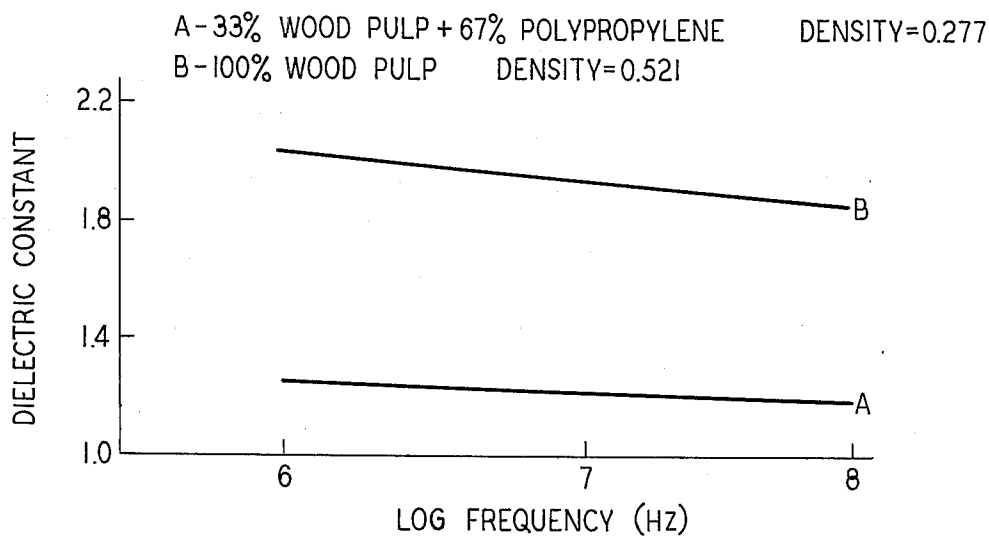


FIG. 6

WOOD PULP + POLYPROPYLENE FIBERS + NO BINDER

**FIG. 7**

WOOD PULP + POLYPROPYLENE FIBERS + NO BINDER



CONDUCTOR WITH INSULATIVE LAYER COMPRISING WOOD PULP AND POLYOLEFIN FIBERS

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my co-pending application, Ser. No. 359,743, filed May 14, 1973, now abandoned, which was a continuation of my application Ser. No. 921,427, filed Nov. 24, 1970, also now abandoned.

FIELD OF THE INVENTION

This invention relates to insulated communications conductors, and more particularly concerns an insulated conductor with improved high frequency characteristics over telephone pairs.

BACKGROUND OF THE INVENTION

The two principal insulation materials for telephone conductors in use today are wood pulp and polyethylene. Wood pulp insulation has acceptable dielectric properties at voice frequencies, and is hygroscopic. Thus, water entering a pulp-insulated multipair cable causes the pulp to swell, which localizes the water at the fault point. Routine tests based on the electrical discontinuities caused by the wet pulp are then employed to accurately locate the fault. However, polyethylene insulation has no wet-swelling property, and hence no built-in mechanism for detection and isolation of water incursions.

On the other hand, in the increasingly important frequency range from 100 kHz to about 20 MHz, the dielectric properties of wood pulp are not favorable. In particular, the dissipation factor of pulp produces a high component of attenuation due to loss in the dielectric. This component is approximately 11.6 dB per mile for a 22 gauge cable pair at 3 MHz compared to 0.3 dB per mile for polyethylene insulated conductors. Furthermore, with varying temperatures, pulp cables exhibit large variations in dielectric loss, capacitance, and capacitance unbalance to ground. The dielectric losses in pulp also show wide and nonlinear changes in the frequency range of interest.

These deficiencies make the use of pulp insulated conductors in the telephone trunk and loop plant unsuitable for high-frequency transmission systems such as T2 carrier and visual telephone service transmission.

It is well known to form a dielectric layer consisting of wood pulp and polyolefin fibers on a supportive tape, and to then apply the composite structure as a wrapping around a conductor. In the wood pulp wet slurry insulating process, however, a ribbon of wood pulp mat is formed from a water slurry onto a wire, without drying, calendaring or the use of a supporting carrier. In the described preformed tape process, tensile strength is supplied by the supportive tape; whereas in the wood pulp process, the tensile strength must be derived from the wood pulp itself and from binders where necessary.

The idea of simple addition of polyolefin fibers in the slurry of the wood pulp insulating process is implicitly suggested by the prior art. However, addition of polyolefin fibers of essentially uncontrolled size was found to frequently produce an unacceptably weak insulation. In some instances the insulation also exhibited local electrical anisotropies, limiting the insulation usefulness of the material to low frequency transmission.

For example, relatively long fibers show a marked and unexpected tendency to distribute poorly in the slurry processing on existing pulp insulating machinery. One consequence is that the fibers do not occupy available space within the bulk efficiently, and therefore fail to achieve a uniform distribution. More specifically, relatively long polyolefin fibers tend to segregate themselves from the fiber-pulp slurry and float to the top. The polyolefin fibers which are picked up as insulation tend to aggregate in clumps.

Accordingly, a primary object of the invention is to develop a material with improved dielectric performance at high frequencies.

Another object of the invention is to achieve the above object while retaining the wet-swelling and water permeation properties of pulp that are useful in localizing and locating water in a cable due to sheath failure.

A specific object of the invention is to realize an insulated conductor with wet-swelling and water permeation properties as well as substantially lower dissipation factor and dielectric constant in the frequency range from 100 kHz to 20 MHz.

A further specific object of the invention is to realize efficient packing of pairs in conductors insulated with the mentioned improved material.

Another object of the invention is to realize an insulation of the character described in all these objects, and which has in addition a tensile strength-elongation property comparable to that of wood pulp alone.

A still further object of the invention is to devise an improved insulation material of the character described which is compatible with cylinder-type pulp insulating machinery.

A specific object of the invention is to develop an insulation having the following properties:

- low dissipation factor at high frequencies, at least 50% less than pulp at 1 MHz;
- lower dielectric constant than pulp;
- minimal variation of dielectric properties with frequency and temperature;
- uniform material properties from lot to lot;
- low resistance to initial incursion of water for quick fault location;
- water-swelling to create blocking action and fault isolation; and
- capability of being produced from a water slurry and formed directly and homogeneously on a wire to permit using insulating equipment now used for pulp.

SUMMARY OF THE INVENTION

Pursuant to the invention, composite insulation materials including, but not necessarily limited to, wood pulp with polypropylene fibers and wood pulp with polyethylene fibers, have been realized which exhibit substantial improvement over 100% pulp in high frequency dielectric properties. They also exhibit the water permeation and wet-swelling features of pulp alone, which are crucial for fault-locating and localizing. Furthermore, they are adaptable to present cylinder-type pulp wire insulating equipment.

Beneficial reductions in dissipation factor are achieved pursuant to the invention, by a conductor insulation which is 10 to 40 weight parts wood pulp, 80 to 35 weight parts polyolefin and 10 to 25 weight parts binder.

It has been found that, in general, the greater the polyolefin fiber cut length, the more closely will the tensile strength-elongation product approach that of

wood pulp alone. However, it has also been found that the greater the fiber cut length, the more poorly the polyolefin fibers disperse in the slurry, and the greater is the incidence of "clumping" of polyolefin fibers within the applied insulation. The clumps account for the referred-to local electrical anisotropies.

Pursuant to a main aspect of the invention, a satisfactory homogeneous insulation has been achieved, without encountering clumping problems, with a composite wood pulp-polyolefin mixture in which the large majority of the polyolefin fibers are substantially no longer than 3/4 inch and no greater in denier size than 6. Within this constraint, a satisfactory tensile strength-elongation product has been achieved substantially by the addition of a binder which comprises substantially from 10 to 25 weight percent of the total insulation on the wire.

The invention, its further objects, features and advantages will be fully understood from a reading of the detailed description to follow of illustrative embodiments thereof.

THE DRAWING

FIG. 1 is a schematic perspective of a Fourdrinier paper machine modified for wire insulating purposes;

FIG. 2 is a schematic cross-sectional view of a wire cluster just prior to wrapping or "polishing" the insulating ribbon around the conductors; and

FIGS. 3-7 are graphs depicting typical electrical characteristics pertaining to insulated wire made pursuant to the invention.

DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

For purposes of illustration, the Fourdrinier insulator machine schematically depicted in FIG. 1, which is of a type that normally applies pure wood pulp to conductors, is used in the present invention to apply mixtures of wood pulp fibers and synthetic polymer fibers to wires. The teaching applies equally, however, to the cylinder type wood pulp insulating machine of the type described, for example, in U.S. Pat. No. 1,762,941 issued to Edward Wood on June 10, 1930.

A slurry consisting of wood pulp fibers and polyolefin fibers in water is prepared and charged into the head box 1. A group of wires 2, which are, for example, 22 gauge copper wires, are fed from a source 2a under a guide roll 2b into the slurry as it leaves the apron or weir 3, and onto a conventional Fourdrinier table 4. The latter consists of a continuous wire screen belt 5 mounted on rollers 6, 7. On the screen the insulation is laid down in parallel ribbons formed by channel member 8. Each wire picks up a coating consisting of a mat of intermingled wood pulp fibers and polyolefin fibers, the result being pictured in FIG. 2.

Uniformity of fiber distribution in the coating is aided by agitating the slurry, by adding small amounts of surfactants and dispersing agents, and by selecting the fiber length and denier size of the polyolefin fibers in a manner to be described. The newly formed mat loses the bulk of its water by means of a vacuum channel 9 and, thereafter, rollers 10. From here the wire and ribbon units are processed in a polisher 11 which wraps the insulating ribbon around the conductor in a spiral lap fashion to provide a continuous, uniform, cylindrical covering. Advantageously, a binder spray head 12 stationed after the polisher 11 applies a spray of binder to the passing insulated conductors in proportions by

weight to be described shortly. Then, after drying in oven 13, the insulated wires are taken up on spools 14.

In general sulfate wood pulp is suitable for use in the present invention and is characterized, typically, by the following:

Tensile strength	2500 psi
Alpha cellulose content	8170 (min)
Alpha cellulose plus lignin content	86% (min)
Fiber geometry	0.3 by 1.2 mils (cross section)
Freeness	425 ML (CSF)
Aqueous extract conductivity	45 micromhos (max)
Ash content	0.5% (max)

The polyolefin fibers advantageously are either polyethylene or polypropylene, of the following typical characteristics:

	Polyethylene	Polypropylene
Tensile strength	50,000 psi	50,000 psi
Elongation	25%	40%
Denier size, average	6.0 max	6.0 max
Fiber length	¾ inch max	¾ inch max
Fiber Density	0.93 g/cc	0.91 g/cc

To produce significant reductions in high frequency dissipation factor and dielectric constant, the amount of polyolefin fiber in the composite material as a proportion of the wood pulp-polyolefin total advantageously is in the range of 10-90 parts by weight. The more desired reductions are obtained with 35-90 parts by weight polyolefin fiber.

Beneficial results in terms of dissipation factor, dielectric constant and tensile strength-elongation factor are realized in a conductor having an insulative layer of from 10 to 40 parts by weight of wood pulp, from 80 to 35 parts by weight of polyolefin fibers and a binder comprising from 10 to 25 parts by weight. Within the foregoing, it has also been realized that a favorable level of wet-swelling property is achieved when the wood pulp is present in at least about 25 parts.

A dielectric insulative material composed of 67 parts by weight of polypropylene fibers and 33 parts by weight pulp when tested at 3 MHz, exhibited a reduction of 83% in dissipation factor ($\tan \delta$) and of 37% in dielectric constant (ϵ') compared to 100% pulp.

To more precisely determine the electrical properties of insulative materials as taught by the present invention, sample sheets A - F below were made up and tested.

EXAMPLE I

Several batches consisting of flat wood pulp fibers about 0.3 by 1.2 mils in cross section, and flat polyethylene monofilament fibers 0.2 by 0.8 mil cross sectionally were mixed in a water slurry in the proportions by weight shown in Table I below. The binder material was Microthene, a low molecular weight, branched polyethylene resin, chosen for its characteristically low melting point.

Table I

Sample	Percent by weight			Thickness mils	Density grams/cc
	Pulp	PE	Binder		
A	15	75	10	41.5	0.490
B	15	75	10	42.3	0.576
C	25	65	10	42.5	0.480
D	35	55	10	43.5	0.497
E	35	55	10	42.0	0.545

Table I-continued

Sample	Percent by weight Pulp	PE	Binder	Thickness mils	Density grams/cc
F	100	0	0	41.0	0.521

Prior to sheet formation all fibers were washed and blended in distilled water. Sheets were formed and bonded under pressure at 120°C. for 3 minutes, which was sufficient to melt the binder but not the polyethylene fibers.

The composite sheets so formed were then tested for ϵ' and $\tan \delta$ at frequencies of 1, 5, 10, 20, 30 and 50 MHz. The variations of ϵ' and $\tan \delta$ with frequency under constant room ambient conditions are shown in FIGS. 3 and 4 respectively.

It is seen that large improvements in magnitude and linearity of ϵ' and $\tan \delta$ are obtained as the percentage of polyethylene fibers is increased. Referring to curve C of FIG. 3, the dielectric constant of 3 MHz for a 25-65-10% by weight mixture is 1.60 compared to 2.24 for 100% pulp. This is an absolute reduction of about 30%. If an ϵ' of 1.0 is taken as a base, the reduction is more than 50%. In the case of $\tan \delta$ at 3 MHz for the same mixture (see curve C of FIG. 4), a value of 0.006 is obtained compared to 0.028 for 100% pulp. This represents a reduction of more than 75%. An even greater improvement is obtained at the higher frequencies. Additionally, the variation of ϵ' and $\tan \delta$ with frequency are much less for all pulp-polyethylene mixtures than for 100% pulp.

FIG. 5 shows the effects of mixture proportions on $\tan \delta$ at 1 MHz and 10 MHz. The points at 0% pulp were obtained on substantially 100% polyethylene sheets. In general the curves are nearly linear, showing that $\tan \delta$ is closely proportional to the percent by weight of pulp contained in the composite sheet. The polyethylene fibers and binders have such a low $\tan \delta$ that for all practical purposes they act substantially the same as air in determining $\tan \delta$ performance when mixed with pulp.

Dielectric strength tests at 60 Hz showed an average value of about 96 volts per mil for the composite sheets, compared to about 130 volts per mil for 100% pulp. The dielectric strength does not appear to be related to the percent of polyethylene present, but rather to the density of the sheet.

With respect to the specimen sheets of Example 1, the electrical tests showed that insulations composed of mixtures of pulp and polyethylene fibers with a polyethylene binder have high frequency dielectric properties that improve about linearly with the amount by weight of polyethylene present. Thus, a mixture of 50% polyethylene and 50% pulp has a dissipation factor approximately one-half of that of 100% pulp. Improvements of a similar nature are obtained in the case of ϵ' . Of equal importance is the great improvement in linearity with frequency of both $\tan \delta$ and ϵ' compared to 100% pulp. Due to the similarity in electrical properties between polyethylene and polypropylene, the same general conclusions as above can be stated for mixtures of wood pulp and polypropylene fibers. This has been substantiated with tests on various mixtures of pulp and polypropylene as illustrated in Example 2.

The specimen batches A-E of pulp-polyethylene mixtures, and a specimen of 100% pulp beaten to 530 mil-CFS, were tested for tensile strength, elongation at

break and water permeation. The water permeation tests gave a comparative measure of the time required for passage of water through the flat side of the sheets under a head of about one-half inch. The results are shown in Table II below.

Table II

Specimen from Tab. I	Density	Thickness mils	Tensile Strength psi	Elongation %	Water Permeation sec/mil
A	.490	40.1	456	12.0	1.8
B	.576	42.5	1268	8.4	2.2
C	.500	41.7	650	11.4	0.48
D	.499	42.1	1099	9.4	0.14
E	.546	43.5	784	8.6	0.21
F	.520	41.0	2500	3.5	0.33

The water permeation tests show that the composite sheets do transmit water, the tests demonstrate the retention by the pulp-polyethylene composite of the useful wet-swelling property found in pulp alone.

It is seen that elongation properties of the pulp-polyethylene composites are more favorable than for pulp, which for conductor insulating purposes tends to counteract the decrease in tensile strength. It is this fact which establishes the pertinence of the tensile strength-elongation factor. Wood pulp alone is highly satisfactory in respect to this factor. It has been found, however, that a tensile strength-elongation factor down to about half that of wood pulp alone is acceptable as an insulative material covering a wire. The sample H-4 of Table III on page 14 exemplifies this finding.

EXAMPLE 2

Sheets consisting of 33 parts pulp fibers and 67 parts polypropylene fibers were prepared by a process similar to that described in Example 1 except that no binder was used. For these sheets, FIG. 6 shows the variation of dissipation factor and dielectric constant with frequency. The curve for 100% pulp is included for comparison. Large improvements in dielectric properties are evident, similar to those for pulp-polyethylene mixtures.

In the blending process, in general, undrawn fibers are preferred over drawn fibers although either type may be used. For good dispersion in a water slurry the polyolefin fibers should be precoated with a dispersing agent. Additionally, a small amount (20 drops per 1500 ML of 0.15% slurry) of the agent added to the pulp slurry prior to blending has been found highly beneficial. Dispersing agents that have been found satisfactory include those known by the trade names "Igepal CO-430" available from GAF Corporation, and "Triton X-114" available from Rhom-Haas. It further has been found necessary to avoid the formation of air bubbles or vortexes during the blending process, since otherwise the polyolefin fibers do not disperse uniformly. Thus it was found that blending by lateral and vertical agitation is to be preferred to circular agitation.

To produce an insulation with an adequate tensile strength-elongation product, one expedient is to add a binding material to the pulp-polyolefin composite. Preferred binders are a cross-linkable latex copolymer (Celanese resin CPE-5271), an acrylic latex, 45% solids (Rhom-Haas HA12) and a styrene-butadiene emulsion, 50% solids (Uniroyal No. 3595). The referred to HA12 gives good pulp-to-pulp binding and the No. 3595 gives good polypropylene binding. Blends

of the latter two binders of this type in an approximately 50—50% by weight mixture are advantageous. The CPE-5271 binder provides good adhesion to both pulp and polyolefin fibers. Curing of the binders is accomplished by heating at temperatures of 100°–125° C. It has been found that the higher the temperature, the shorter the curing time.

Binders of low melting point polyolefins in powder or emulsions also are useful. For example, a Microthene branched polyethylene used with heat and pressure gave good results from the standpoint of providing tensile strength. Powders or emulsions made from amorphous polypropylene having melting points less than 125° C. also may be employed. Emulsions are easier to use than the powders since they will readily mix and remain in contact with the pulp and polyolefin fiber blends. The binders may be added to the slurry mixtures prior to formation on the wire or after the polishing operation on the insulated wire. The latter method, known as "saturation addition" is preferred in some situations.

A general lower limit of substantially any binder of the types mentioned, is approximately 10 parts per 100 weight parts of the composite insulation. In about this amount, the binder's contribution to the tensile strength-elongation product is disproportionately larger than the contribution of binder when present in 6 or 8 parts per 100 parts by weight, as can be seen by reference to Table III. The binder used for specimens H-1 through H-7 was a standard commercial acrylic latex copolymer.

Table III

Sample	Composition			Relative Product of Tensile Strength and Elongation
	% Pulp	% PP	% Binder	
Control	100	—	—	100
H-1	47	53	—	15
H-2	45	49	6	23
H-3	46	46	8	34
H-4	44	45	11	57
H-5	45	40	15	103
H-6	41	41	18	142
H-7	37	37	26	148

The tensile strength-elongation data of Table III is normalized around a control figure of 100 for wood pulp alone. A lower limit for this figure of no less than 50 is workable and acceptable as applied to pulp-polyolefin-binder composites, as exemplified by the samples H-4 through H-7. Thus binder parts per 100 by weight of 10, 11, 15, 18 and 26 and all values in between are all increasingly acceptable in terms of the resulting tensile strength-elongation product. From an electrical standpoint, however, at approximately 25 parts of binder per 100 parts by weight of composite insulation, the increase in density and the increase in lossy material tracing to the binder plus the pulp, was found to be so much that the advantage of the polyolefin fibers present in the composite was canceled. This thus establishes the upper practical limit of the binder proportion at about 25 parts per 100 parts by weight of composite insulation. Further verification of this general upper limit of binder proportion is found in Example 9 later in this specification.

The Table III data is based on a composite comprising polypropylene fibers of 3 denier size, ¼ inch cut length. However, further tests have demonstrated that substantially the same conclusions just stated will apply

if the fibers are polyethylene. Likewise, the same conclusions apply to fibers within the critical ranges of 1.0 to 6.0 denier and 1/6 inch-¾ inch cut length which are established elsewhere in this specification.

EXAMPLE 3

Polypropylene fibers of 3-denier size and 1/8-inch long are precoated with a dispersant. Wood pulp fibers are placed in a blender in a water slurry to a concentration of 0.15%, to which 20 drops of dispersant per 1500 milliliters are added. Then, the polypropylene fibers are added to the slurry in amounts sufficient to net a 50—50% by weight blend of pulp and polypropylene. During blending, air bubbles and vortexes are avoided by horizontal and vertical agitation rather than circular. The slurry is piped to the head box (1 in FIG. 1) of a Fourdrinier wire insulating machine and passes over the apron to the areas where ribbons are formed. The wires are laid on the ribbons of insulation and advance with the screen 5 to the polishing equipment. The polisher wraps the ribbon around the wire in a continuous spiral fashion giving a continuous uniform insulating coating. The polishing operation also removes a substantial portion of the remaining moisture in the insulation. Leaving the polisher, the wires must be damp but not wet with water. This is important from the standpoint of binder absorption, which is the next step. If the insulation is either too wet or too dry, binder absorption will be impaired. For this purpose it has been found that moisture contents in the range of 40 to 90% by weight are satisfactory.

From the polisher, the wire passes through the binder applicator. This may be either spray or roller-type equipment and is provided with controls of binder concentration and rate of application to yield a takeup advantageously of approximately 20% by weight in the composite insulation. Thus when the wire enters the dryer it contains approximately 40% pulp, 40% polypropylene fibers and 20% binder. Drying at 125° C. will cure the binder and provide essentially a moisture-free insulation of the above composition.

A critical lower value of 1.0 on denier size and of 1/16 inch on fiber cut length is herein taught because the resulting insulation demonstrates no tendency to clump and because—as a practical matter—no smaller sizes or lengths of fiber are commercially obtainable at present. At the upper end, it has been found that a choice of nominal polyolefin fiber cut length substantially in excess of ¾ inch and/or denier size in excess of 6.0, yields an unacceptable insulation, as will be demonstrated below.

Several specimens of wood pulp-polypropylene sheet identified as specimens G-N in Table IV were prepared having approximately the same densities and thicknesses but having no binder since for the purpose of this example a binder was not necessary. The fiber cut length for the two denier sizes, 3 and 6, was varied in steps from 1/8 inch to ¾ inch for 3-denier fibers and from ¼ inch to 7/8 inch for 6-denier fibers. In the 3-denier specimens G-K, as cut length varies, the tensile strength-elongation product is seen to go through a minimum of 1411 at 3/8 inch cut length. At this minimum, the dispersion was found to be optimum as demonstrated by visual analysis: that is, the greatest degree of homogeneity of sheet structure was evident with no clumping of polypropylene fibers. As cut length varies either way, the tensile strength-elongation product improves, but at about ¾ inch electrically minor but still

discernible signs of macroscopic heterogeneity, or clumping become evident.

Further samples denoted O-R in Table V were prepared each with substantially the same fiber cut length but of varying denier size. By visual observation of the sheet structure, gross inhomogeneities, or clumps, were evident in the 6-denier size, 7/8-inch cut specimen N, and in the 8- and 15-denier size specimens Q and R. However, all of the other specimens G, H, I, J, K, L, M, O, and P did not exhibit clumping.

Table IV

Sample	Mixture %Pulp %PP		Fiber Length Denier In.		Product of Ten- sile Strength & Elongation
G	63	37	3	1/8	2337
H	62	38	3	1/4	1897
I	63	37	3	3/8	1411
J	62	38	3	1/2	1641
K	62	38	3	3/4	2512
L	62	38	6	1/4	2101
M	62	38	6	1/2	2630
N	62	38	6	3/4	3484

Table V

Sample	Mixture %Pulp %PP		Fiber Length Denier In.		Product of Ten- sile Strength & Elongation
O	62	38	3	1/2	1641
P	62	38	6	1/2	2630
Q	62	38	8	3/4	3796
R	62	38	15	1/2	3753

The experimental methods used, as well as several examples of experiments which led to the above results relating to fiber dispersion, will now be cited.

SPECIMEN PREPARATION

All samples cited in Tables III, IV, and V were made by first preparing a water slurry consisting of the desired proportions by weight of wood pulp fibers and polyolefin fibers. Uniform dispersion of the fibers in the slurry was sought in a magnetic mixer using a magnetic mixing bar. The mixed slurry was then fed into the bath of an 8 inch $\times$ 8 inch Williams sheet mold. Using a quick-release drain, water was removed and the sheet was formed from the solids in the slurry. The mixing and blending steps are exactly analogous to those practiced in the standard cylinder type wire insulating process. Each sample was then conditioned for about 3 days at 50 percent relative humidity and 72° F. preparatory to electrical and mechanical testing.

TENSILE STRENGTH TESTS

Conditioned specimens of the samples of Tables III, IV, and V, were cut into strips 6 inches $\times$ 4 inches. An Instron tensile strength tester was used with an initial jaw separation of 2 inches. A recording chart speed of 10 inches/minute and a crosshead speed of 1 inch/minute was used. Each sample was thus tested until failure. The numerical results appear in the Tables III-V, and their implications have already been discussed.

EXAMPLE 4

A water slurry of substantially equal parts of wood pulp fibers and 15-denier size, 7/8-inch cut length polypropylene fibers was prepared to a medium concentration and mixed magnetically as described above. Pronounced clumping of fibers at the top of the slurry was

observed visually. The slurry was mixed with agitating action stopping just short of forming a vortex. Still, pronounced clumping was observed. The concentration was diluted by the addition of 1/3 more water, with no discernible reduction in the clumping. Sheets were prepared as above. The sheets formed with irregularly spaced fiber clumps in large numbers. The forming sheets lost their water very rapidly, creating a sheet with a highly rippled, uneven surface. Rigorous electrical tests were performed to measure dielectric constant on 10 samples, each a 1-1/2 inch diameter disc. Discs exhibiting a high degree of clumping had a dielectric constant of about 2.0, which approaches the dielectric constant of raw polypropylene. Discs with low clumping densities exhibited a dielectric constant of 1.8. The dielectric constant values of 1.8 to 2.0, and the spread of 0.2, are unacceptably high.

EXAMPLE 5

A water slurry of wood pulp fibers and 6-denier size, 3/4-inch fiber cut length polypropylene fibers was prepared as in Example 4. The observed clumping was greatly reduced both in density and clump size over Example 4. Addition of 1/3 more water noticeably reduced the clumping further. A minor extent of ripples in the dewatered sheet was observed. Dispersion of all fibers on the prepared sheet was, in the main, uniform. Electrical tests were made on 10 1-1/2 inch diameter sample discs, to determine dielectric constant, yielding readings from 1.7 to 1.85. The spread of 0.15 represents at least a substantial improvement over the 0.2 spread of Example 4.

EXAMPLE 6

A water slurry of wood pulp fibers and 3-denier size, 1/2-inch fiber cut length polypropylene fibers was prepared as in Example 4. Dispersion in the mixed slurry was visually observed to be substantially uniform, with no need to reduce the concentration. Slight agitation of the slurry in the sheet forming mold was quite sufficient to maintain good dispersion. The water was seen to drain away uniformly for all parts of the forming sheet. Ripples were present but barely discernible, being of greatly reduced size over those of Example 5. Dielectric constant measurements on 10 1-1/2 inch diameter discs yielded readings in a range from 1.58 to 1.65, a spread of 0.07. This range is preferred because within it a highly advantageous thin 9-mil thickness of insulation on a wire will yield the standard mutual capacitance of 0.083 between members of an insulated pair. The spread is also fully acceptable for reliable high frequency performance.

EXAMPLE 7

A water slurry of substantially equal parts of wood pulp fibers and 3-denier size, 1/4-inch polypropylene fibers was prepared in the slurry vat of a standard cylinder-type insulating machine. Ribbons were formed on the cylinder, and then directly dried and tested at a large number of points to determine the uniformity of dispersion of the wood pulp and polypropylene fibers, using a differential scanning calorimeter. The lowest reading reflected the presence of 47 percent polypropylene fibers, and the highest reflected presence of 52 percent polypropylene fibers. Most readings were at or much closer to 50 percent. These readings reflect a high degree of uniformity in dispersion. Electrical tests corroborated that the dispersion uniformity was more

than enough. The experiment was continued by forming ribbons of the composite insulation around conductors. After drying, the dielectric constant of the thus-formed insulation tested out to be 1.6 ± 0.02 , a very acceptable situation.

From these data it follows that in general composite pulp-polyolefin mixtures to be used in a water slurry for insulation of wire characterized by favorable high frequency properties, should be of an average denier size not substantially in excess of 6.0 and of a fiber cut not substantially in excess of $\frac{3}{4}$ inch. Polyethylene and polypropylene were both found to exhibit substantially the same clumping propensity as a function of fiber length and denier size.

The use of fiber cut length of $\frac{3}{4}$ inch or less, and of denier size 6.0 or less is necessary in general as a control on maintaining the homogeneity of the insulation, over the entire already-mentioned range of parts by weight of 10 to 40 wood pulp, 80 to 35 polyolefin and 10 to 25 binder, within which the beneficial levels of dissipation factor, dielectric constant and tensile strength-elongation factor are present. The specific parts by weight of wood pulp, polyolefin and binder in a given case will be determined by: how great a wet-swelling factor is needed, how large a dissipation factor can be tolerated, how large a tensile strength-elongation factor is required, how much binder existing machinery can tolerate without alteration, and other factors which are principally matters of engineering tradeoff and economics.

To assess the effect of relatively high and low concentrations of binder in a composite insulation of wood pulp, polyolefin and binder, the tests of Examples 8 and 9 were performed.

EXAMPLE 8

A sheet was prepared pursuant to the procedure of Example 4 from a slurry of wood pulp and $\frac{1}{8}$ inch, 3-denier size polypropylene fibers. No clumping at the top of the slurry was observed. Acrylic latex binder obtainable as HA12 from Rhom-Haas was added to the sheet such that the resulting sheet composition when dried was 44 weight percent wood pulp, 45 weight percent polypropylene fibers, and 11 weight percent binder. The sheet was examined for fiber dispersion which was observed to be favorably uniform with no clumps. Three samples were taken from the prepared sheet. Tensile strength, percent elongation and tensile strength-elongation product were measured and calculated for each. Elongation was superior to that of a pulp control sample. Tensile strength was inferior. The product, averaged for the 3 samples, was 2470 as compared to a product of 4300 for the pulp control sample. The average product was acceptable, although for some conductor insulation purposes more strength would be desirable. Tests for dissipation factor and dielectric constant were made. Dielectric constant over a frequency range of 0.001 to 30.0 MHz varied between 1.2666 and 1.238, with a low occurring at 1.230. Dissipation factor measured between 0.002 and 0.006. These data compare favorably against corresponding data in FIG. 4 for 100% wood pulp.

EXAMPLE 9

Three samples from a sheet were prepared as in Example 8, except that the resulting sheet composition when dried was 36% pulp, 36% polypropylene and 28% binding agent. No clumping at the top of the slurry was observed. The finished sheet was visually examined and exhibited uniform fiber dispersion with no clumping. Tensile strength-elongation factor measured 6130, well above the characteristic 4300 of wood pulp alone. Dielectric constant measurements were between 1.338 and 1.301, which is acceptable. Dissipation factor, however, at 10 MHz was 0.007, having increased with frequency very rapidly. The resultant product was judged unacceptable due to the extreme borderline value of dissipation factor at 10 MHz, tracing in turn to the high percent weight of binder in the product.

It has further been observed that use of polyolefin fibers of substantially $\frac{1}{4}$ inch or less and of denier size 6.0 or less supply a further and unexpected advantage of forming a pine-needlelike outer envelope of protruding fiber ends on the insulation. These outer ends when later oven dried were microscopically observed to collapse down and tend to mechanically tie up the surface pulp and fibers, thus lending firmness to the insulation while still keeping it loose enough to maintain its wet-swelling property. It has been visually and experimentally observed, however, that this effect is not achieved when the fibers are less than about $\frac{1}{8}$ inch in length. The use of polypropylene fibers of substantially $\frac{1}{4}$ inch or less and of denier size 6.0 or less supply the further and unexpected advantage of forming a pine-needlelike outer envelope of protruding fiber ends on the insulation, which when later oven-dried will collapse down and tend to mechanically tie up the surface pulp and fibers, thus lending firmness to the insulation while still keeping it loose enough to maintain its wet-swelling property. This desirable property is realized only when the fibers are not significantly less than $\frac{1}{8}$ inch in length and 1.0 in denier size.

The spirit of the invention is embraced in the scope of the claims to follow.

What is claimed is:

1. A conductor having an insulative layer comprising from 10 to 40 parts by weight of wood pulp, from 80 to 35 parts by weight of polyolefin fibers and from 10 to 25 parts by weight of a binder, said polyolefin fibers being characterized by a denier size not substantially greater than 6.0 and a fiber length not substantially greater than $\frac{3}{4}$ inch.

2. The insulated conductor claimed in claim 1, wherein the wood pulp is at least 25 parts by weight.

3. The insulated conductor claimed in claim 1, wherein the polyolefin fiber is polypropylene.

4. In combination: a conductive element surrounded by an insulative layer comprising from 10 to 40 parts by weight of wood pulp, from 80 to 35 parts by weight of polyolefin fibers and from 10 to 25 parts by weight of a binder, said polyolefin fibers being characterized by a fiber length of substantially between $\frac{1}{8}$ inch and $\frac{1}{4}$ inch and by a denier size of not greater than 6.0.

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