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Plate

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[54] ELECTRICAL CABLE

[75] Inventor: **Walter J. Plate**, Rye, N.Y.

[73] Assignee: **The Anaconda Company**, New York, N.Y.

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[51] **Int. Cl.** **H01b 7/18**
[58] **Field of Search** .... 174/102 SC, 120 R, 120 SR, 174/120 SC, 110 AR, 110 S, 110 R, 110 PM, 120 AR, 36, 106 SC, 107

[56] **References Cited**

UNITED STATES PATENTS

3,187,071	6/1965	Padziejowski	174/120 AR
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FOREIGN PATENTS OR APPLICATIONS

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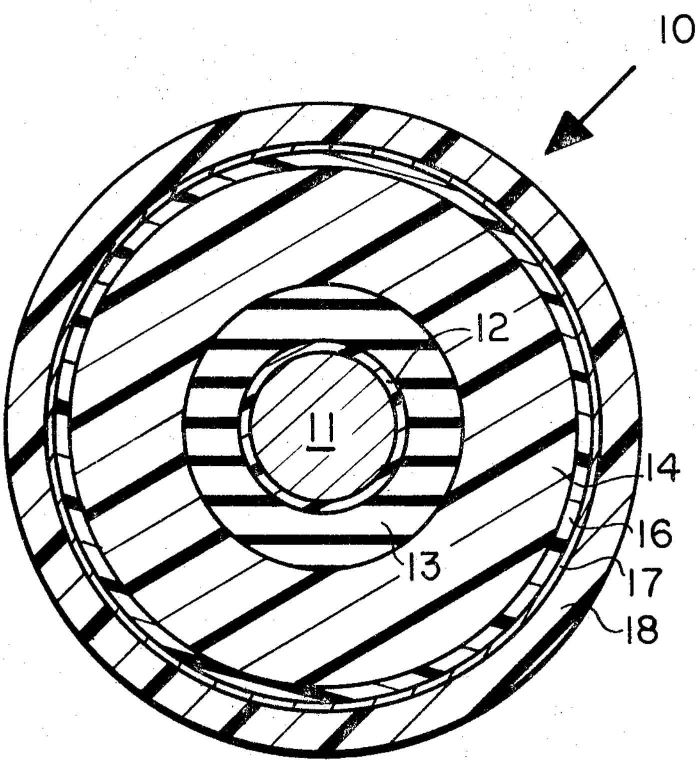
Primary Examiner—E. A. Goldberg
Attorney, Agent, or Firm—Victor F. Volk

[57] ABSTRACT

An electric power cable comprises extruded strand shielding and an inner layer of rubber insulation such as ethylene-propylene copolymer or ethylene-propylene-diene terpolymer rubber bonded by cross-linking to an outer layer of cross-linked polyethylene insulation.

16 Claims, 2 Drawing Figures



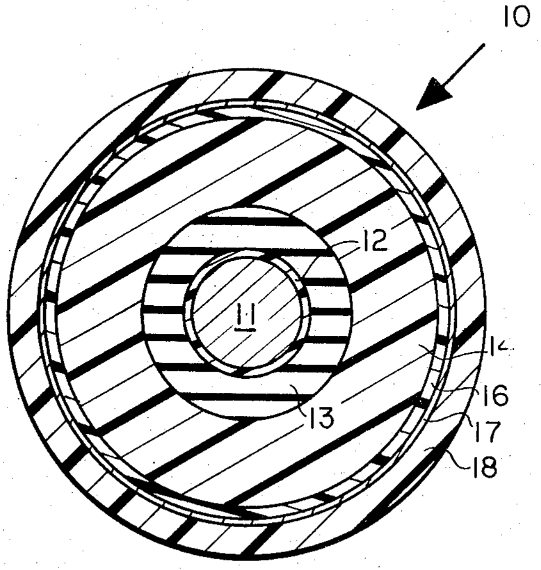


Fig. 1

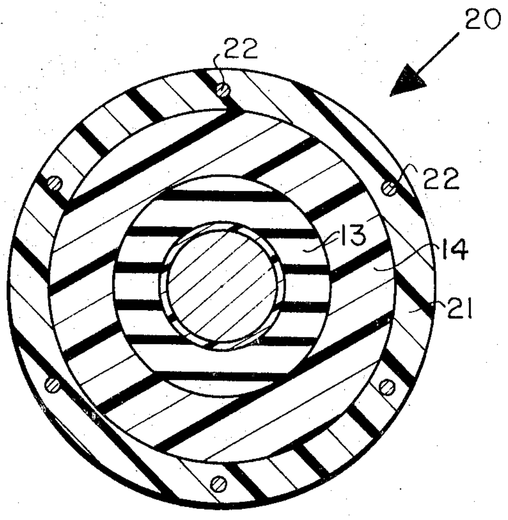


Fig. 2

ELECTRICAL CABLE

BACKGROUND OF THE INVENTION

It has been known to insulate electric power cables with polyethylene incorporating a cross-linking agent, such as di-α-cumyl peroxide, and to heat the cables so insulated so as to form cables with non-thermoplastic polyethylene insulation. Non-thermoplastic, cross-linked polyethylene does not evidence the stress cracking associated with thermoplastic polyethylene and functions satisfactorily at higher temperatures. Although millions of feet of cross-linked polyethylene cable do operate without fault, some deficiencies of cross-linked polyethylene have been noted. For example, cross-linked polyethylene does not resist corona attack as well as certain rubbers. Cross-linked polyethylene has a high elastic modulus that makes cables having thick walls of such insulation relatively stiff and inflexible. It expands considerably when heated and may evidence the phenomenon of "treeing" under the electrical stresses encountered in normal operation.

Cables have also been successfully made with ethylene-propylene and ethylene-propylene-diene rubbers, known respectively as EPM and EPDM, for insulation. These materials behave like other rubbers in having a high flexibility and retention of physical properties at elevated temperatures and have high resistance to corona attack. They do not expand as much upon heating as does polyethylene but neither do they have as high a dielectric strength as the latter. EPM and EPDM do not extrude smoothly unless they have been compounded with a filler, such as clay, and this has the effect of raising the specific inductive capacitance (S.I.C.) of the composition to a value greater than that of polyethylene. While the rubberiness or resilience of EPM and EPDM has the advantage of making cables more flexible, polyethylene has greater toughness and resistance to deformation at ordinary cable temperatures.

SUMMARY OF THE INVENTION

I have invented a cable that has excellent corona resistance on the inside of the insulation, where the electrical stresses have their highest values, and expands less on heating in this area, where the conductor generates high temperatures. On the outside, the insulation retains a relatively hard, tough consistency, during installation and normal operations, characteristic of cross-linked polyethylene. My new cable comprises a metallic conductor, a layer of extruded strand shielding surrounding the conductor, a layer of ethylene-propylene copolymer or ethylene-propylene-diene rubber surrounding the layer of strand shielding, a layer of cross-linked polyethylene insulation surrounding the layer of rubber and a polymeric jacket surrounding the outer layer of insulation. The rubber comprises blended filler material that increases its specific inductive capacitance (also known as "dielectric constant") to a value of above 3 and the rubber and polyethylene layers bond to each other at their interface by molecular cross-linking, accomplished by a common cross-linking agent such as di-α-cumyl peroxide. In a preferred embodiment of my invention the jacket comprises a semiconducting composition extruded directly over the layer of polyethylene.

A useful embodiment of my invention comprises a metallic conductor, preferably with a layer of semiconducting strand shielding surrounding the conductor, and an inner layer of rubber-based insulating composition, surrounding the conductor and any semiconducting strand shielding, and having a 100 percent modulus at 130° C of at least 50 percent of its 100 percent modulus at 25° C. An outer layer of vulcanized polymer-based insulating composition surrounds and bonds to the inner layer. This outer layer composition has a 100 percent modulus at room temperature substantially higher than the 100 percent modulus at room temperature of the inner layer composition, and a 100 percent modulus at 130° C substantially lower than the 100% modulus at 130° C of the inner layer composition. Preferably the inner layer composition comprises filler material blended therewith, thereby increasing its specific inductive capacitance to a value above **3**, substantially exceeding the specific inductive capacitance of the outer layer composition. The inner and outer layers of this cable preferably comprise a common cross-linking agent such, for a preferred example, as di-α-cumyl peroxide, and, in a preferred embodiment, a semiconducting polymeric jacket directly surrounds the outer layer.

BRIEF DESCRIPTION OF THE APPENDED DRAWING

FIG. **1** shows a section of a cable of my invention.

FIG. **2** shows a section of another embodiment of the cable of my invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The cable **10** comprises a metal conductor **11** which may have a stranded or solid configuration, surrounded by a layer **12** of extruded semiconducting polymeric composition having a smooth cylindrical outer surface. The layer **12** may consist of thermoplastic or vulcanizible compositions or have partial vulcanization as described in Arnaudin et al. U.S. Pat. No. 3479446, incorporated herein, by reference. Directly over the layer **12** I have extruded the layer **13** of a synthetic rubber composition based on either EPM or EPDM.

The term EPM has widespread usage commercially for rubbers formed by copolymerizing ethylene and propylene, and the term EPDM has widespread usage commercially for terpolymers that include, in addition to ethylene and propylene, a relatively small proportion of a diene. U.S. Pats. No. 2933480 and 3151173, incorporated herein by reference, enumerate a number of suitable dienes, such as hexadienes and norbornadienes. A review of the art of EPM and EPDM referred to generically therein by the term "polyolefin elastomers" appeared in an article by F.P. Baldwin and G. Ver Strate in Vol. 45, No. 3, Apr. 30, 1972, of Rubber Chemistry and Technology, pp 709–881. The compositions of the layer **13** incorporate, in addition to the usual minor compounding ingredients, a di-α-cumyl peroxide for cross-linking and 20–60 percent by weight of filler, such as clay filler, intimately dispersed. The filler has the function of reducing the nerve of the rubber composition so that it will extrude smoothly but it also has the effect of increasing the specific inductive capacitance. As I shall explain, the higher S.I.C. proves to have an advantage in my new cable construction.

Over the layer **13** I have extruded a layer **14** of polyethylene insulation also incorporating di-α-cumyl peroxide for cross-linking. Heating for vulcanization of the insulation does not proceed until I have extruded both layers **13** and **14**, with the results that, since they both employ the peroxide for cross-linking, the layers cross-link together at their interface in a firm bond. This bonding prooves to have great importance to the superior performance of the cable **10** since the layer **14** of polyethylene has a much higher thermal coefficient of expansion than the rubber layer **13** and would separate from the layer upon heating in the absence of a bond. Separation of the layers would create voids within which corona discharges would occur when the cable becomes highly stressed electrically. I have applied a semiconducting layer **16**, preferably formed of extruded polymeric compound, directly over the layer **14** to constitute the insulation shielding layer, and this has a covering of copper or aluminum shielding tapes **17**, covered, in turn, by an extruded protective jacket **18**. I can use any of a number of known cable jacketing materials for the jacket **18** of which I consider compositions based on polyvinyl chloride, neoprene, and butyl rubber as particularly suitable. In FIG. **2** I have shown a similar cable **20**, differing from the cable **10** by the omission of the layers **16–18** for which I substitute a semiconducting polymeric jacket **21** having embedded drain wires **22**, such as I have joined in describing in Plate et al. U.S. Pat. No. 3474189.

Examples 1 and 2 respectively exemplify embodiments of the constructions of FIGS. **1** and **2**.

EXAMPLE I

35 kV Cable

	Layer Thickness Inch, Min.	Diameter Inch Nominal
Bare copper, compact round	—	0.481
Extruded strand shielding	0.008	0.503
EPDM rubber	0.118	0.748
Polyethylene cross-linked	0.228	1.219
Insulation shielding	0.030	1.289
Bare copper tapes	0.003	1.297
Polyvinyl chloride jacket	0.080	1.468

EXAMPLE II

35 kV Cable

	Layer Thickness Inch, Min.	Diameter Inch Nominal
Bare copper, compact round	—	0.481
Extruded strand shielding	0.008	0.503
EPDM rubber	0.118	0.748
Polyethylene, cross-linked	0.140	1.041
Extruded semiconducting jacket	0.085	1.220

6 No. 17 Awg. copper drain wires

The cables of Examples I and II exhibited the S.I.C. and power factors listed in Table I at the tabulated temperatures and electric stresses.

TABLE I

	Example I		Example II	
volts/mil	S.I.C.	%p.f.	S.I.C.	%p.f.
Room temperature				
20	2.68	0.170	2.74	0.360
40	2.68	0.208	2.74	0.361
60	2.68	0.211	2.74	0.365
80	2.68	0.215	2.74	0.369
90° C				
20	2.51	0.489	2.58	0.620
40	2.51	0.495	2.58	0.625
60	2.51	0.510	2.58	0.631
80	2.51	0.515	2.58	0.638
130° C				
20	2.38	0.830	2.43	0.931
40	2.38	0.855	2.43	0.949
60	2.38	0.871	2.43	0.965
80	2.38	0.885	2.43	0.979

The power factors of the tables of Examples I and II varied with frequency as tabulated in Table II at the indicated temperatures.

TABLE II

	Example I		Example II	
Hertz at room temperature	S.I.C.	%p.f.	S.I.C.	%p.f.
60	2.82	0.240	2.82	0.350
100	2.79	0.190	2.85	0.330
1,000	2.79	0.145	2.84	0.250
10,000	2.78	0.148	2.82	0.230
100,000	2.77	0.298	2.82	0.280
Hertz at 90° C				
60	2.60	0.500	2.65	0.670
100	2.63	0.350	2.66	0.550
1,000	2.62	0.200	2.64	0.330
10,000	2.61	0.151	2.63	0.240
100,000	2.61	0.229	2.63	0.240
Hertz at 130° C				
60	2.46	0.890	2.54	1.080
100	2.50	0.630	2.55	0.770
1,000	2.48	0.285	2.53	0.370
10,000	2.47	0.170	2.51	0.235
100,000	2.46	0.160	2.51	0.265

In Table III I report the results of loading the cable of Example I to 100° C conductor temperature 8 hours each day for 100 working days in accelerated aging tests, while applying A-C voltage equal to two times rated voltage to ground continuously throughout the duration of the test. The table reports properties monitored prior to current loading at the beginning of each day.

TABLE III

		Corona		20 v./mil.		60 v./mil.		100 v./mil.	
Time on test	Cable temp. °C.	Level A*	(kV) B*	SIC	Percent pf.	SIC	Percent pf.	SIC	Percent pf.
Intial	26.0	50.0	Clear	2.71	0.138	2.71	0.200	2.71	0.200
1 day	26.7	50.0	Clear	2.70	.165	2.71	.209	2.71	.207
7 days	29.0	50.0	Clear	2.69	.150	2.69	.190	2.69	.197
14 days	27.8	50.0	Clear	2.68	.110	2.68	.141	2.68	.135
28 days	28.5	50.0	Clear	2.67	.086	2.67	.119	2.67	.118
42 days	25.2	50.0	Clear	2.67	.082	2.67	.112	2.67	.104
70 days	25.0	50.0	Clear	2.67	.068	2.67	.098	2.67	.093

Example I - current loading: 483 amperes
*A=Inception B=Extinction

Table IV tabulates the results of testing the cable of Example II following the procedure of Table III.

TABLE IV

Time on test	Cable temp. °C.	Corona Level (kV) A*	Corona Level (kV) B*	20 v./mil. SIC	20 v./mil. Percent pf.	60 v./mil. SIC	60 v./mil. Percent pf.	100 v./mil. SIC	100 v./mil. Percent pf.
Initial	26.0	50.0	Clear	2.73	0.315	2.73	0.281	2.73	0.280
1 day	26.7	50.0	Clear	2.72	.197	2.72	.256	2.72	.268
7 days	28.8	44.0	43.0	2.69	.240	2.69	.202	2.69	.196
14 days	27.8	43.5	42.7	2.68	.170	2.68	.154	2.68	.140
28 days	28.5	43.0	41.5	2.67	.176	2.67	.133	2.67	.125
42 days	25.2	50.0	Clear	2.66	.171	2.66	.124	2.66	.115
70 days	25.1	50.0	Clear	2.67	.122	2.67	.101	2.67	.104

Example II - current loading: 514 amperes

Table V tabulates the results of immersing the cable of Example I in water at 90° C and testing at the indicated intervals.

TABLE V

Time immersed	40 v./mil. SIC	40 v./mil. Percent pf.	80 v./mil. SIC	80 v./mil. Percent pf.	1000 Hz. SIC	1000 Hz. Percent pf.	I.R. meg-ohms–M'
24 hours	2.62	0.436	2.62	0.520	2.69	0.216	10,247
7 days	2.62	.443	2.62	.502	2.67	.224	3,760
14 days	2.62	.393	2.62	.465	2.64	.220	5,683
28 days	2.64	.475	2.64	.525			5,260
2 months	2.65	.607	2.65	.624			3,420

Table VI tabulates the results of immersing the cable of Example II in water at 90° C and testing at the indicated intervals.

TABLE VI

Time immersed	40 v./mil. SIC	40 v./mil. Percent pf.	80 v./mil. SIC	80 v./mil. Percent pf.	1000 Hz. SIC	1000 Hz. Percent pf.	I.R. meg-ohms–M'
24 hours	2.62	0.907	2.62	0.803	2.61	0.274	5,357
7 days	2.59	.365	2.59	.360	2.61	.262	4,513
14 days	2.60	.720	2.61	.720	2.61	.242	4,573
28 days	2.58	.300	2.58	.303			3,747
2 months	2.64	.500	2.64	.563			3,400

Table VII reports the results of immersing the cable of Example I in water at 90° C for two months while stressed at 34.6 kV, A-C.

TABLE VII

Time immersed	40 v./mil. SIC	40 v./mil. Percent pf.	80 v./mil. SIC	80 v./mil. Percent pf.	1000 Hz. SIC	1000 Hz. Percent pf.	I.R. meg-ohms–M'
24 hours	2.60	0.442	2.60	0.500	2.68	0.216	10,563
7 days	2.60	.452	2.60	.501	2.66	.227	6,700
14 days	2.61	.400	2.61	.430	2.67	.223	5,800
28 days	2.63	.493	2.63	.525			4,617
2 months	2.64	.753	2.64	.753			4,946

Table VIII reports the results of immersing the cable of Example II for two months in water at 90° C while stressed at 34.6 kV, A-C.

TABLE VIII

Time immersed	40 v./mil. SIC	40 v./mil. Percent pf.	80 v./mil. SIC	80 v./mil. Percent pf.	1000 Hz. SIC	1000 Hz. Percent pf.	I.R. meg-ohms–M'
24 hours	2.61	0.611	2.61	0.675	2.63	0.244	6,000
7 days	2.60	.340	2.60	.410	2.63	.241	4,680
14 days	2.60	.576	2.61	.791	2.63	.229	4,666
28 days	2.60	.559	2.61	.721			3,647
2 months	2.63	.721	2.64	.920			3,317

A terpolymer formulation suitable for the layer 13 has the composition of Table IX.

TABLE IX

	pts. by wt.
Nordel* 1040	100
carbon black	10
silicone treated clay	110
lead oxide	5
silane	1
antioxidant	1.5
zinc oxide	5
paraffinic oil	15
paraffin	5
di-α-cumyl peroxide	3.5

*Nordel has been registered as a trademark of E.I. du Pont de Nemours & Co., Inc. for ethylene-propylene-diene terpolymers. Nordel 1040 comprises 1–4 hexadiene, according to the literature of the supplier.

A copolymer formulation suitable for the layer 13 has the composition of Table X.

TABLE X

	pts. by wt.
Vistalon* 404	100
zinc oxide	5
Translink**	110
carbon black	10
Agerite*** Resin D	1.5
PbO_2	3
silane	1
di-α-cumyl peroxide	2.7
sulphur	0.3

* registered as trademark of Enjay Chemical Co. for ethylene-propylene copolymer.

** registered as trademark of Freeport Kaolin Co. for silicone treated clay.

*** registered as trademark of R.T. Vanderbuilt Co., Inc. polymerized trimethyldihydroquinoline antioxidant.

The copolymers and terpolymers suitable for use in the layer 13 will have molecular weight, prior to vulcanization, of 100,000 to 1,000,000 and an ethylene content between 25 and 75 mole percent. In addition, I may blend them with as much as about 15 percent of polyethylene but not so much as to destroy the rubbery nature of the composition characterized by a relative retention of modulus upon heating. In modern art usage and in this application the word "rubber" distinguishes polymers, having a resilient property and also exhibiting a substantially flat modulus vs temperature curve, from thermoplastics, such as polyethylene, which, even after cross-linking, drop sharply in modulus with increasing temperature. Persons skilled in rubber and plastic technology employ the 100% modulus at a given temperature as a reproducible parameter, convenient for comparing different materials. They determine the 100% modulus as the stress in load-per-unit-section required to elongate a specimen 100%. A chart of the 100% modulus, in pounds per square inch, of butyl and EPM rubbers and filled and non-filled cross-linked polyethylene over a range of temperatures appears in IEEE Transactions on Power Apparatus and

Systems, April, 1968, page 1,142, and I include this chart by reference in this application. The chart shows polyethylene to have a substantially higher 100 percent modulus at room temperature than the rubbers, but a substantially lower modulus,when non-filled, than the rubbers at 130° C. At 130° C the 100 percent modulus of polyethylene drops to less than one-third its value at 25° C while the 100° percent modulus of EPM at 130° C exceeds its value at 25° C. For usefulness in the cable of my invention the 100 percent modulus of the composition of the rubber layer **14** should not drop more than about 50 percent between 25° and 130° C. Rubber compositions that retain their modulus at increased temperature and can have utility in the practice of this invention, may incorporate minor proportions of polyethylene or other thermoplastic materials. Particularly up to about 30 parts of polyethylene may be incorporated into the EPM or EPDM compositions of my layer per hundred parts of rubber, within the scope of my invention. Similarly, my outer layer **14** may comprise small proportions of rubber. Particularly, a polyethylene composition used for the layer **14** may incorporate up to about 30 parts of EPM or EPDM for 100 parts of polyethylene. An additional terpolymer formulation suitable for the layer **13** and used as the EPDM composition in Examples I and II appears in Table XI.

TABLE XI

	pts. by wt.
Nordel 1040	100.0
polyethylene	10.0
Translink	120.0
carbon black	5.0
litharge	6.0
antioxidant	1.0
paraffin	3.0
paraffinic oil	10.0
silane	1.5
di-α-cumyl peroxide	3.0
sulphur	0.3

The flat temperature modulus curve of rubbers, hereinabove noted, has particular value for high-voltage cables with thick walls of insulation because such insulation constitutes a heat barrier confining heat generated by the conductor. For this reason my invention has particular utility in cables with a radial insulation thickness of at least 250 mils.

I determine the addition of clay or other filler to the rubber composition by processing requirements and generally do not exceed the quantity required for good extrusion except that I do not add less than the quantity required to bring the S.I.C. of the composition above 3. The S.I.C. of the composition of Table IX tested at about 3.9, so that processing, rather than grading requirements determine the practical filler content. Persons skilled in rubber compounding can calculate the percentage of filler to be added to achieve a desired S.I.C. of a rubber composition from the known S.I.C. values of the filler material and the uncompounded polymeric stock.

From the high initial corona inception values of Tables III and IV it becomes clear that the bond at the interface between the inner EPDM and outer polyethylene layers has not parted in spite of the fact that the polyethylene has a much greater coefficient of thermal expansion than the terpolymer. The inner layer, due to its clay inclusion, has an S.I.C. of about 3.9 while the polyethylene has an S.I.C. of about 2.3. My cable thus gains the advantage of "grading" by having a greater S.I.C. material adjacent to the conductor where the

greatest stress concentration appears. In prior art attempts to employ polymers for purposes of grading a cable insulation, a discontinuity or void has always become evident between the layers having different polymeric bases. A unique feature of my invention resides in the bonding together of layers of different polymers forming compositions of different S.I.C. by means of a common vulcanizing agent that cross-links across the layer interface.

For the cross-linking agent of Examples I and II I used di-α-cumyl peroxide, but other vulcanizing agents can be used within the scope of my invention provided only that they can affect the cross-linking of both the rubber layer **13** and plastic layer **14** so that the two bond together. A number of suitable vulcanizing agents for olefins have been enumerated in U.S. Pats. No. 2,888,424 and 3,036,982 which I incorporate herein, by reference.

In the manufacture of my cable I extrude four different layers over the conductor: the strand shielding **12**, the rubber insulation **13**, the polyethylene insulation **14**, and the insulation shielding **16**. I may accomplish all these extrusions within one extrusion head of appropriate known design, or may pass the core having each extruded layer directly into another extrusion head to apply the next layer. I may also practice combinations of such multiple and tandem extrusions. For example, I may apply the strand shielding in one head, and follow with a dual application of the rubber and polyethylene insulation, followed, in turn, by tandem application of the insulation shielding **16**. The same range of choices applies to the cable **20** with the strand shield replaced by the jacket **21**. I always apply the jacket **18**, of course, in a tandem or separate operation.

I have invented a new and useful electric cable of which I have made the foregoing description exemplary rather than definitive, and for which I desire an award of Letters Patent as defined in the appended claims.

I claim:

1. An electric cable comprising:

A. a metallic conductor,

B. a layer of semi-conducting strand shielding surrounding said conductor,

C. a layer of insulation selected from the group consisting of ethylene-propylene copolymer and ethylene-propylene-diene terpolymer rubbers surrounding said layer of strand shielding,

D. a layer of electrically insulating cross-linked polyethylene insulation surrounding said layer of rubber and bonding thereto, and,

E. a polymeric jacket surrounding said layers of insulation.

2. The cable of claim 1 wherein said rubber layer comprises ethylene-propylene copolymer.

3. The cable of claim 1 wherein said rubber layer comprises ethylene-propylene-diene terpolymer.

4. The cable of claim 2 wherein said copolymer comprises filler material blended therewith, thereby increasing the specific inductive capacitance of said copolymer to a value above 3.

5. The cable of claim 3 wherein said terpolymer comprises filler material blended therewith, thereby increasing the specific inductive capacitance of said terpolymer to a value above 3.

6. The cable of claim 1 wherein said layers of insulation bond to each other at their interface by molecular cross-linking.

7. The cable of claim **6** wherein said layers of insulation comprise a common cross-linking agent.

8. The cable of claim **7** wherein said agent comprises di-α-cumyl peroxide.

9. The cable of claim **1** wherein said jacket comprises a semiconducting composition applied directly over said layer of polyethylene.

10. An electric cable comprising:

A. a metallic conductor,

B. an inner layer of rubber-based insulating composition surrounding said conductor, said composition having a 100 percent modulus at 130° C of at least 50 percent of the 100 percent modulus of said composition at 25° C,

C. an outer layer of vulcanized polymer-based insulating composition surrounding said inner layer,

  a. said outer layer bonding to said inner layer,

  b. said outer layer composition having a 100 percent modulus at room temperature substantially higher than the 100 percent modulus at room temperature of said inner layer composition,

  c. said outer layer composition having a 100 percent modulus at 130° C substantially lower than said 100 percent modulus at 130° C of said inner layer composition, and

  d. the modulus at 130° C of said outer layer composition not exceeding one-third of the modulus at 25° C of said outer layer composition, and

  e. said inner and said outer layers together totaling at least 250 mils in radial thickness.

11. The cable of claim **10** comprising a layer of semiconducting strand shielding surrounding said conductor under said inner layer and bonding to said inner layer.

12. The cable of claim **10** wherein said inner layer composition comprises filler material blended therewith, thereby increasing the specific inductive capacitance of said inner layer composition to a value above 3, said value substantially exceeding the specific inductive capacitance of said outer layer composition.

13. The cable of claim **10** wherein said inner and outer layer compositions comprise a common cross-linking agent.

14. The cable of claim **12** wherein said inner and outer layer compositions comprise a common cross-linking agent.

15. The cable of claim **10** comprising a semiconducting polymeric jacket directly surrounding said outer layer.

16. The cable of claim **14** wherein said cross-linking agent comprises di-α-cumyl peroxide.

* * * * *