WESTERN UNION Technical Review

The Plastics Story

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Tickets by Telefax

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Microwave Propagation

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Wire and Cable

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JULY 1953

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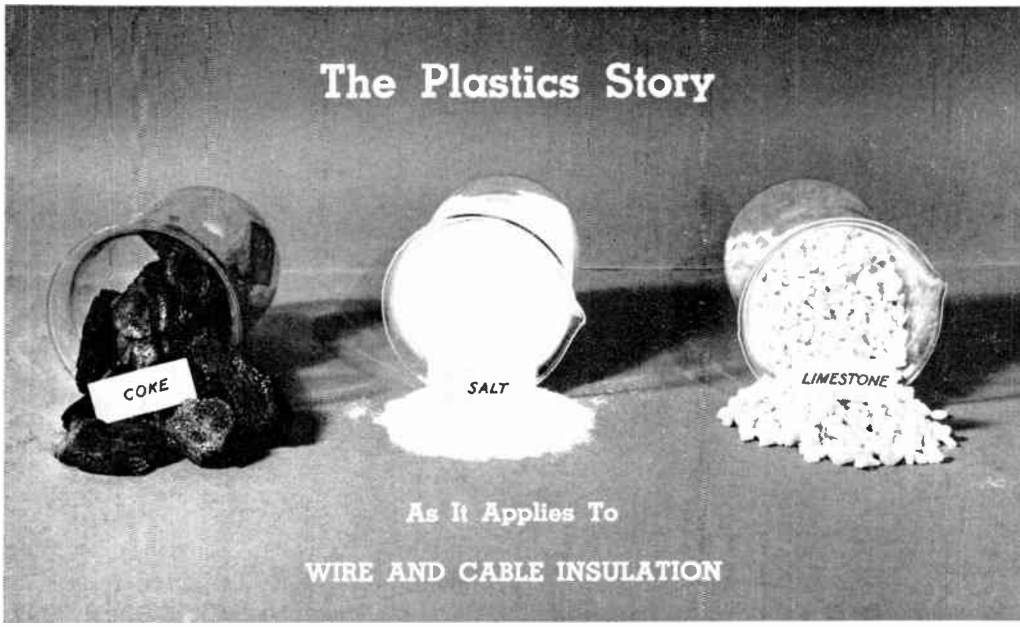


W. E. BURKE

NOT LONG AGO, a large manufacturer of automobiles employing plastics extensively for parts, ventured the suggestion, "Expect the impossible of plastics". Such optimism may be extravagant but in view of the work accomplished with these materials in the past 10 or 15 years, not only in the automotive field but also, more pertinently, in the domain of wire and cable coverings of which this paper treats, such an estimate of the potentialities of plastics may not be too far afield. Indeed it might be apropos, at this point, to quote from the work of Calvin E. Schildknecht on *Vinyl and Related Polymers.* He mentions the development of polytetrafluoroethylene as a good example, to the industrialists of the twentieth century, of accomplishing the impossible in plastics research. The advance in knowledge of plastics is an outstanding achievement in the field of modern organic chemistry.

This paper will discuss plastic materials which have been under study either to develop their over-all adaptability for wire and cable insulation and jacketing, or to ascertain their usefulness for special applications. The work was carried on in Western Union's laboratories, one of the outstanding communication research centers, located in New York and at Water Mill, Long Island. In these laboratories studies are ever in progress of electronic devices and of materials, including wire and cable insulations, toward the end of providing the ultimate in service to the public and the nation over the vast network which Western Union controls.

PRIMARY CONSIDERATIONS

It is, of course, elementary but a convenient introduction to point out that the purpose of applying insulating coverings to wire carrying electric currents is to prevent escape of these currents to surrounding media. To accomplish this end, materials which have nonconducting properties are used as wire coverings. The electric current streaming through the conductor under the insulating sheath may be compared to water forced through a hose which directs its flow. If the hose is intact, no leakage of water occurs, but if porous or cracked, water leaks through and escapes. Similarly, an insulating material which has good insulation resistance will not permit seepage of current through its body, but if poor electrically, leakage of current will be in accordance with the extent of its electrical porosity.

Among the insulating materials ordinarily used for many years rubber is predominant but mention may be made of paper, enamel, textiles, and even of glass tubing for insulating conductors, as well as of gutta percha for insulating submarine cables. In recent years, materials have come into wide use which are described as plastics, a term applied by industry to certain new resins having, as an outstanding property, ease of molding. It is true, however, that the name has been extended to such materials as paints and adhesives having formulations which include such resins, so that the terminology covers a rather broad field. Actually the word *plastic*, stemming from Greek and Latin roots and translated as "moldable", was in ancient times applied to ceramics. Definitions of the term plastic that have been advanced currently are usually described as tentative, because of the new materials which they are designed to cover and the fact that plasticity, moreover, is a complex property.

A typical definition is that ventured in a *Handbook of Plastics*, by Herbert R. Simonds and Carleton Ellis. This definition describes a plastic as *a synthetic organic material whose chief component is a resinous or cellulose derivative binder. At some stage in its production, it is either plastic (capable of being shaped) or liquid (capable of being cast) and at some subsequent stage it assumes a more or less rigid condition.* This generic term plastics may be broken down into two categories: thermoplastic materials which, incidentally, include such materials as vinyls and acetates, as well as glass, wax and unvulcanized rubber; and thermosetting materials which embrace phenolics and ureas. The former are heat fusible; that is, subject to change in form from soft to hard whenever exposed to increase or decrease of temperature, without sustaining any chemical changes in the process. The latter are heat infusible and once subjected to heat and pressure in the mold, undergo chemical changes which render them impervious to further softening by heat. The plastic qualities of the two materials may be aptly compared, respectively, to sealing wax and to concrete. Thermoplastic materials, like sealing wax, may be a hard dense mass at room temperatures but become soft and pliable under heat; on the other hand, thermosetting materials, like concrete, once hardened remain in that state permanently.

When World War II broke out, a serious rubber shortage threatened that, unless relieved, portended disaster, since natural rubber at that time was the elastomer generally in use. Actually, the fall of Singapore on February 15, 1942, cut off about 95 percent of our natural rubber supplies. This event accelerated the development of synthetic rubber, resulting in the introduction of new types and more extensive use of those already available. Of the synthetic rubbers, GR-S, a copolymer of butadiene and styrene, is outstanding as a general purpose compound. The specialty synthetic rubbers comprise the oil-resistant compounds, Neoprene and Buna N, the latter also known by the trade names of Butaprene, Chemigum, Hycar and Perbunan; butyl rubber, having airtight properties which adapt it particularly for inner tubes and is used to some extent for high-voltage circuits of 2000 volts and above; and silicone rubber, resistant to heat, cold and chemicals as well as oxidation, and having exceptionally good water-repellent properties.

Concurrently with the work on synthetic rubber, research was accelerated on thermoplastic insulating materials which gradually came to the fore as insulation for wire and cable. The materials used presently by Western Union for inside wire and cable insulations are almost entirely thermoplastic; those now employed in the outside plant still include rubber for pothead cable and paper and rubber insulation for certain other types of cable, but thermoplastics are gradually replacing the older forms of outside insulating and jacketing materials.

The formulations for insulating materials are tailored to provide desired properties. They are carefully designed by the wire manufacturer for qualities which are most important for the particular usage to which the conductor is to be applied.

It might be pointed out that thermoplastic coverings may be applied to wire not only as primary insulation, but also as secondary or jacketing materials; both usages will be considered in this paper. Primary wire insulation compounds must be of a nature to provide good electrical properties, must not be harmful to the conductor, and must resist deformation; jacketing compounds, because they are applied in heavier walls, must have good flexibility, toughness and abrasion resistance.

The effectiveness of primary insulation hinges particularly on the resistance which it affords to the passage of current and on high dielectric strength. The materials must also be adapted for such conditions as operating voltage, load rating, ambient temperatures and exposure to light and moisture to which they may be subjected in service.

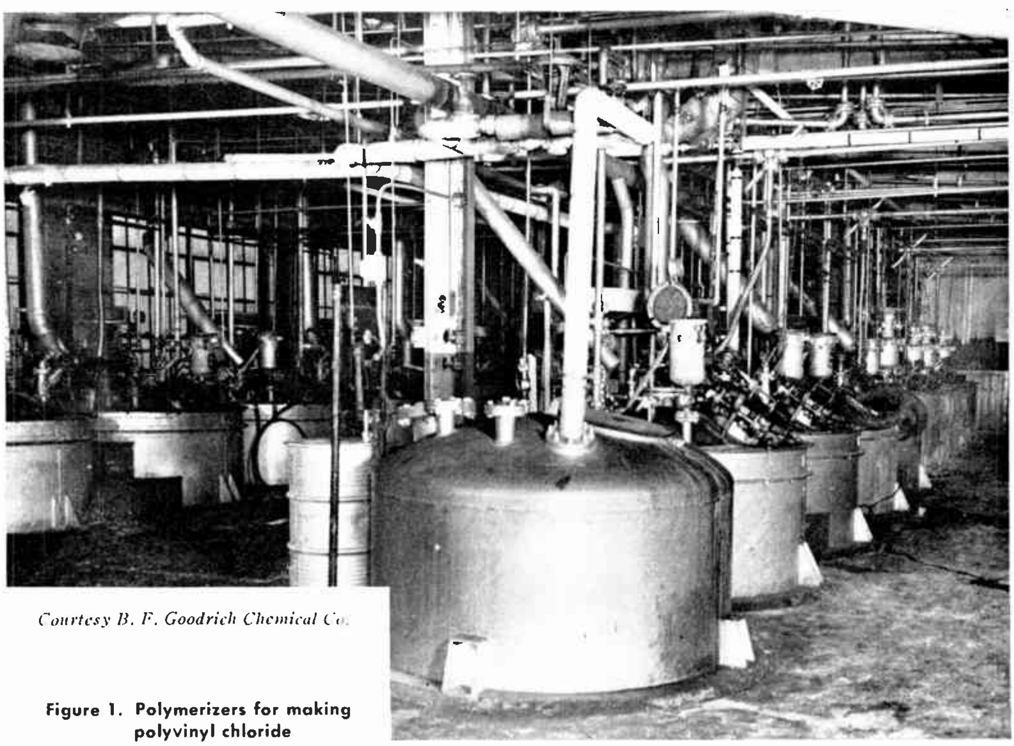
INSULATING MATERIALS

A brief discussion of various plastic compounds which have been under study in Western Union's Development and Research laboratories is given in the ensuing paragraphs. These compounds include vinyl, polyethylene, polyethylene derived, fluorocarbon and nylon compounds.

Vinyl Compounds

Chronologically, vinyl plastics originated in 1838 when vinyl chloride, which was exposed to sunlight, was found to have produced a white powder. Other vinyls which were unaffected by solvents or acids came into the picture in 1872. It was not until 1912, however, that vinyl compounds of the elastomer type were evolved and a period of 15 years elapsed before vinyl resins became commercially available. The picture at the beginning of this article displays graphically the basic ingredients of polyvinyl chloride.

Chemical research developed that the molecule of vinyl chloride has the ability to combine with itself to form giant chain-like molecules, comparable to a string of paper clips. The process of hooking up of these molecules to form larger molecules of chain structure is described chemically as polymerization. A polymerizer for making polyvinyl chloride is shown in Figure 1.



Courtesy B. F. Goodrich Chemical Co.

Figure 1. Polymerizers for making polyvinyl chloride

Such a process is commonly employed by nature to add strength to materials. Cobwebs, shellac, the cellulose which imparts structural properties to wood, and a vast array of common objects are natural polymers.

When compounded with other ingredients, resins such as polyvinyl chloride or polyvinyl chloride plus polyvinyl acetate formed thermoplastic materials that proved well adapted for extrusion on wire and cable. Such compounds, moreover, have the advantage, from the standpoint of wire and cable insulation, of toughness,

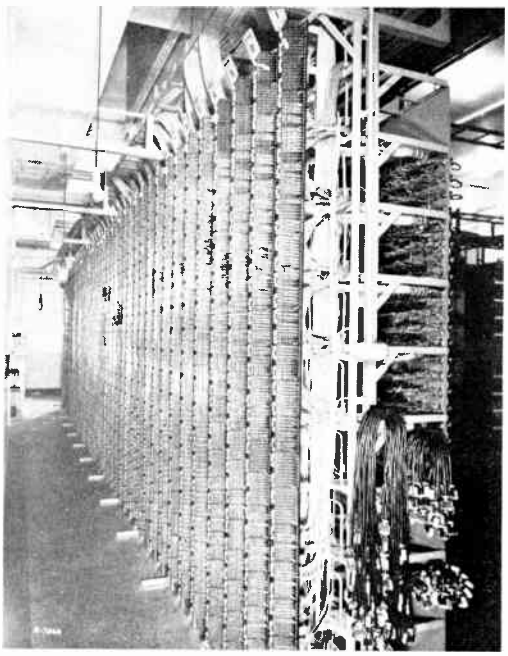


Figure 2. Distributing frame wired with thermoplastic insulated conductors

stability to light and heat, good weathering, good aging properties and ease of fabrication. Vinyl compounds account by far for the most extensive use for wire and cable insulation and jacketing in the Telegraph Company plant. The annual usage by the company of No. 22 and No. 24 gage wire alone, insulated with vinyls, may run from five to ten million feet. Figure 2 shows a distributing frame wired with vinyl insulated conductors illustrative of the volume of plastic insulated conductors used in the Western Union plant. Additional examples of application of thermoplastic materials as insulating and jacketing materials for wire and cable are described in Mr. W. F. Markley's paper on *Wire and Cable in the Telegraph Industry* appearing serially in current issues of TECHNICAL REVIEW.

A simple analogy compares the compounding of the vinyl resins to the baking of a cake. The several ingredients, resin, stabilizer, lubricant, plasticizer, filler and colorants are ordinarily placed, in that respective order, in a blender in which they are intimately mixed. It can be said that the resin may fittingly be compared to flour which form it resembles when it reaches the molder; that the stabilizer has a function like that of baking powder in the mix overcoming thermal breakdown of the resin during the processing operation: that the lubricant, like grease on a cake pan, prevents sticking of the compound in mill or Banbury mixing operations (See Figure 3): that the plasticizer adds the important property of flexibility to the compound and may be compared to shortening; that the coloring matter acts like the vegetable colors used for pigmenting in cake baking; and that the fillers may imaginatively be compared to flavoring extracts. The materials are first mixed and then kneaded in a Banbury mixer, much the same as dough is treated. Just as a cake will char or burn if exposed to excessive temperatures for a long period of time, so vinyl compounds when subjected to heat may be spoiled in extrusion for similar or other causes, even though the compound itself may be of highest quality. The functions of the various components of polyvinyl chloride are discussed in greater detail in paragraphs that follow.

The electrical properties of the finished compound are dependent to a large extent upon the concentration of plasticizer employed and on the type of plasticizer. Of the vast array of plasticizers available, tricresyl phosphate (TCP) and dioctyl phthalate (DOP) are most commonly used and have more to offer than other plasticizers. Often, however, more than one plasticizer is used where a combination of the peculiar properties of each is desired. Some plasticizers may, for instance, improve low temperature flexibility or flame resistance or reduce migrating tendencies.

It might be of interest to point out that as plasticizer content is increased, insulation resistance is decreased. This phenom-

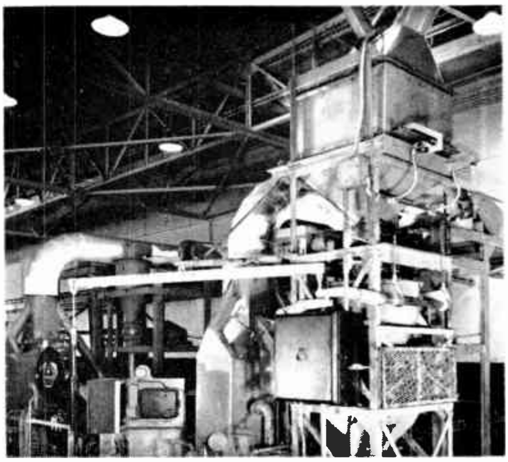


Figure 3. Banbury mixer used at the Western Electric Company's Point Breeze Works, Baltimore, Md.

enon is attributable to decrease in stiffness of the compound as the plasticizer content in the formulation increases, which condition allows the conducting ions greater freedom of motion and thus raises conductivity. Dielectric strength is slightly decreased and ultimate elongation increased with higher percentages of plasticizer. Some plasticizers may even, on heating of the compound, free by-products which have a corrosive influence on a copper conductor.

One characteristic of a plasticizer, too, is its migration tendencies which, if sufficiently pronounced, may have a detrimental effect on the physical properties of the compound. In Western Union laboratory tests of plasticizer migration made under an oven temperature of 167 degrees F, which is the highest normal temperature experienced in Western Union service, it was found that the loss of plasticizer in the wire samples under test was greatest during the first one or two months of the test period and tapered off sharply thereafter. Indications based on these tests are that the total loss of plasticizer in a good compound would not be great enough in a 10-year period to result in any serious degree of deterioration of the compound.

The most undersirable effect of plasticizer migration, however, is diffusion of plasticizer from one material to another when the two materials are held in contact for a long period with possible deterioration of the compound which absorbed the plasticizer. An illuminating instance of plasticizer diffusion that recently came to our attention occurred when, due to wicking action, a plasticizer was found to have exuded into the marker thread between insulation and jacket of a conductor throughout the length of a coil. The use of a resinous type of plasticizer, incidentally, tends to overcome migration but presents other disadvantages.

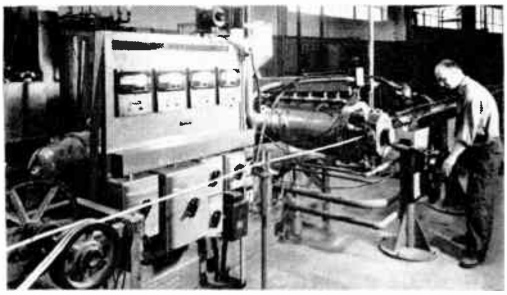
In order to overcome decomposition of the resin under the heat to which it is subjected in processing, stabilizers are included in the compound. Stabilizers commonly used at the present time are tribase dythal, dyphose and basic carbonate of white lead. The amount of stabilizers required is about 10 percent by weight of the resin. For example, in a formulation specifying 50 percent resin, by weight, 5 percent stabilizer is commonly used.

A small amount of lubricant on the order of 1.0 percent, added to an insulating compound, not only facilitates mixing but also increases extrusion speed. Lead stearite is commonly employed for this purpose. This material should be of the fused instead of the precipitated type since the latter contains a small percentage of sodium salts which sharply degrades insulation resistance.

Finally, fillers may be incorporated in compounds to lower material costs, to help speed up extrusion rate, or to provide certain specific properties. The addition of fillers to a compound tends to reduce tensile strength and elongation, to increase durometer hardness, specific gravity, and moisture absorption. The use of fillers also reduces abrasion resistance and flex life. An amount of filler greater than 20 percent by weight will cause degradation of all properties. An excess of 20 percent by weight of fillers is sometimes used where electrical requirements are not critical and low manufacturing costs are important. A nonconducting compound can be made semiconducting by using as a filler 30 or 40 percent of a conducting type of carbon black.

As to colorants, often required for coding purposes, permanence or nonbleeding characteristics are essential. If the colors bleed from one conductor to another in a cabled form, they would lose identity and circuit identification would not be possible. Heat and light stability of colorants are of course important, and pigments in general have a detrimental effect on electrical properties so that colored compounds are poorer, for instance, in insulation resistance. Red in particular has a very degrading effect on electrical insulation.

The power factor of the vinyl compounds varies over a range between 6 and 15 percent and the dielectric constant from 4 to 8. The higher values of power factor and of dielectric constant tend to limit use of the materials to low frequency circuits. Insulation resistance and dielectric strength are good. Altogether, the material is well adapted for communication and hook-up wire insulation and is suitable for most services in the Telegraph Company's plant. In general, those compounds which have a high percentage of vinyl chloride and in addition a high molecular weight are best adapted for use in wire and cable insulating compounds.



Courtesy The Whitney Blake Co.

Figure 4. Wire insulation extruding machine

A word might be said at this time on rigid and semirigid types of vinyl chloride compounds. This material, until recently, has been used largely for such applications as phonograph and dictaphone records, but work is now being done by some of the plastic manufacturers toward developing a rigid vinyl chloride resin adapted for conductor insulation with little or no plasticizer. Tests made in our laboratories of one of these compounds indicated that the compound, as might be expected from its low plasticizer content, has outstanding electrical properties. Moreover, it has excellent flame resistance. The conductor, however, is unduly stiff and difficult to "skin."

The extrusion of polyvinyl chloride compounds as wire insulation was first attempted on conventional rubber extrusion equipment but this procedure was found unsatisfactory. It was necessary to develop a new type of machine for extruding this material (Figure 4 shows a machine in service). Such equipment often includes a device that heats the wire before it passes through the extruder, which eliminates strains that may develop minute cracks on the inner surface of the sleeve of insulation, and at the same time dries out any moisture that might be present on the conductor, thus avoiding minute porosity of the compound which might impair insulation resistance properties. The system also includes a cooling trough and pay-off and take-up reels for the bare conductor and for the insulated wire respectively. Provision is also made for means of adjusting the screw speed to permit regulation of rate of extrusion. The extruder may be run at speeds of 200 to 1000 feet per minute, for instance, for No. 14 gage wire with 2/64-inch wall.

Polyethylene

Polyethylene or polymers of ethylene are described by the chemists as straight chain aliphatic hydrocarbons of various molecular weights. These polymers are closely related to paraffin and have many properties of ordinary paraffin wax. There are important differences, however, which are due to the higher molecular weight of polyethylene resins.

This hydrocarbon was originally developed in England about 1933 and was introduced into the United States in 1940, when, under the aegis of the United States Navy, two plants were constructed to produce it. Its advent here at that time, concurrently with the development of radar, was most opportune. The prime utility of this material currently is wire and cable insulation.

Polyethylene has high dielectric strength, a dielectric constant of 2.3 and a power factor of 0.05 percent over a cycle range from 60 cy to 100 mc. A further advantage of polyethylene as conductor insulation is its inertness to ozone, a property in which rubber, as an insulating material, is seriously deficient.

The compounding operations for polyethylene in contrast with those for vinyl chloride and vinyl chloride-acetate resins are relatively simple. No plasticizer is required for polyethylene, but anti-oxident to stabilize electrical properties under high heat, pigments to produce colors, and carbon black to improve weathering characteristics may be added ingredients to improve its properties.

This material can be extruded easily with conventional equipment. The rate of extrusion is a function of thickness, viscosity of the plastic and other considerations. Extrusion rates for polyethylene may be as high as 1000 feet per minute for wire and about 10 feet per minute for cable of one inch diameter, and extrusion temperatures may range from 400 to 500 degrees F. Extrusion technique and machinery for this material may be the same as for vinyl chloride compounds except for minor changes in the equipment.

Among the advantages of polyethylene, in addition to its excellent electrical properties, are its light weight, toughness, abrasion resistance, and resistance to fatigue due to flexing. Polyethylene, however, has two important drawbacks; the first, a low softening point, 225 degrees F, although efforts have been made to overcome this shortcoming by vulcanizing; and the second, flammability, an undesirable property since it presents a fire hazard. It may be said, concerning vulcanization of polyethylene, that the feasibility of such treatment is highly controversial. Since this hydrocarbon contains practically no unsaturation, it would be very difficult to vulcanize in the ordinary sense of the word.

In spite of the disadvantages cited above, which might appear to disqualify polyethylene as a jacketing material, it is nevertheless used extensively for that purpose. It has for one thing, as a compensating property, the advantage of a sharp softening point which permits use of the compound at temperatures up to 90 percent of the softening point. Then, too, because of its crystalline nature and its freedom from plasticizer, it is not subject to cold flow, in the ordinary sense of the phrase, as are, for instance, the vinyl compounds which may develop a rapid creep or flow under low stress at normal or low temperatures. Polyethylene, however, will flow when stressed beyond its elastic limit, and this behavior is sometimes misinterpreted as cold flow. The flammability of this material cannot be gainsaid, but actually is no greater than that of an oil base compound.

Polyethylene jackets either as outermost or innermost lamina, have been used in the composite sheaths of the respective Alpeth, Lepeth and Stalpeth cables which are now in use in the Bell System. In these cables, additives to improve aging and to overcome degradation of the polymer which takes place in sunlight, have been included in the compound. The plastic manufacturers predict from 20 to 40 years serviceability for these jackets.

During early installations of Alpeth cable, however, a difficulty now known as "environmental cracking" of the polyethylene sheath was experienced. It was found that detergents, used as lubricants, while not harmful to the unstressed polyethylene sheath, produced cracking of the sheath under such multiaxial strains as were set up when the cable was bent around a corner. Investigation developed that the cracking under such conditions was largely a function of molecular weight and that it could be relieved by using polyethylene of a higher molecular weight as well as by incorporation of a small percentage of polyisobutylene.

It might be mentioned in passing that polyethylene has been compounded with butyl rubber to form a thermosetting compound that has advantages over natural or synthetic rubber oil base compounds.

Polyethylene is definitely growing in importance from the standpoint of communication and power wire and cable. The numerous papers on the properties and applications of polyethylene presented at the AIEE Fall General Meeting held in Cleveland, Ohio, October 22 to 26, 1951, serve as an indication of the expanding interest in this material.

Polyethylene Derived Compounds

In addition to polyethylene, there is available a modified polyethylene known as a "polyethylene derived compound," which not only has good electrical properties but has the further advantage of being flame retardant. Flame retardant properties incidentally may be imparted to polyethylene by inclusion of such additives as antimony oxide and chlorinated paraffin in the compound. Samples of wire insulated with this compound have been tested in the laboratory and although the electrical characteristics are somewhat lower than those of polyethylene, because of the additives, they are still of a high order. Radio Corporation of America has prepared specifications for wire insulated with this type of compound as a single-conductor, high-voltage cable of the low-loss, flexible type for use in radio, television and similar electronic apparatus. The compound is well adapted for use where both flame resistance and dielectric properties are important. It can be used for continuous service at temperatures as high as 160 degrees F.

This compound contains no plasticizer and has the low dielectric constant of 2.7 and a power factor of 0.2 percent with a dielectric strength, when tested as required under A.S.T.M. Standard D-149, Method of Test for Dielectric Strength of Electrical Insulating Materials, of 940 volts per mil (thickness 0.060 in.). The freedom from plasticizer also adapts the material as a noncontaminating jacket material.

In addition to treating polyethylene for flame retardance, Diamond Alkali Company of Cleveland, Ohio, have recently developed a technique for so treating polystyrene, natural and synthetic rubber, and cellulose acetate butyrate.

Fluorocarbon Polymers

The initial interest in fluorocarbon plastics as wire insulation developed in the small gage thin wall field, including radio and aircraft wire, ordinarily subjected to high temperatures. These plastics include monochlorotrifluoroethylene (fluorothene) and tetrafluoroethylene. In the former a chlorine atom is substituted for one of the fluorine atoms in the molecule producing a modified fluorocarbon, whereas in the latter the molecule contains only carbon and fluorine and is a pure fluorocarbon.

Monochlorotrifluoroethylene insulated wire that was tested in Western Union Laboratories was found to have excellent resistance to burning, demonstrating that the plastic will not support combustion, i.e., continue to burn after removal of a flame. It also withstood a Western Union heat shock test without impairment and a cold test in which no cracking developed at temperatures down to —70 degrees F. The plastic, moreover, was found to be excellent for nonwetting properties, and therefore has good surface resistivity inhibiting development of conducting paths of moisture on the surface. Incidentally the monochlorotrifluoroethylene plastics can be extruded with standard equipment with only minor modifications.

The electrical characteristics of monochlorotrifluoroethylene are of a high order, the insulation resistance approaching infinity with dielectric strength as high as 1700 volts per mil for a 10-mil wall of insulation, low power factor and low dielectric constant.

Tetrafluoroethylene is the nearest approach to the perfect dielectric yet achieved. Manufacturing costs, however, are extremely high since the plastic cannot be processed with the equipment used for other plastics. Tetrafluoroethylene has electrical properties about as good as those of polyethylene, can be used under operating temperatures as high as 550 degrees F, is flame resistant, solvent resistant and water resistant.

Conductors insulated with the fluorocarbons may make possible even greater miniaturization of electrical equipment than presently exists. Because of the prevailing high costs of these plastics, however, their use in the telegraph plant is limited. Such usage is necessarily restricted to special conditions where high cost may be justified. For example trifluorochloroethylene was used recently for conductors in our submarine cable repeaters where good electrical and physical properties, and especially resistance to oil, are of outstanding importance.

Nylon

Nylon has been defined scientifically as a generic term for any long chain synthetic polymeric amide which has recurring amide groups as an integral part of the main polymeric chain and which is capable of being formed into a filament in which the structural elements are oriented in the direction of the axis. The ingredients of nylon are popularly represented as derivable from coal, air and water. The name is applied to a vast group of chemically related products or materials, the properties of which are designed for a particular purpose. DuPont, for instance, has at least a dozen formulations each of which is adapted for a special utility such as extrusion molding, injection molding, wire insulation, and so forth. Laboratory tests of this material demonstrated that while nylon is poor electrically and therefore unsatisfactory as primary insulation except as magnet wire, it has a definite place as wire and cable jacketing material.

Nylon is now used extensively as a protective coating for polyethylene and polyvinyl chloride compounds on which its excellent abrasion resistance and high film strength render it particularly suitable for thin wall applications. Other advantages that it possesses as a jacketing material are stability at high temperatures, chemical resistance, low temperature flexibility, good surface resistivity and failure to support fungus growth.

Nylon compounds are supplied to the manufacturer ready compounded for a specific application. Nylon is extruded in much the same fashion as other compounds discussed, with such modifications as may be necessary in the equipment to adapt it for its peculiar properties. In extruding nylon, however, the material is drawn around the conductor instead of forced as in vinyl extrusion. Extrusion of nylon may be carried on at very high speeds and in thin walls. An extrusion rate of 1600 feet per minute has been reached, and a wall thickness of one-half mil as a primary coating is feasible.

PHYSICAL AND ELECTRICAL REQUIREMENTS

The important properties that thermoplastic wire insulation for communication conductors must possess, from a performance standpoint, may be gaged from examination of specifications for these wires prepared by Western Union and by such national bodies as Armed Services Electro Standards Agency, Radio Television Manufacturers' Association, American Society for Testing Materials, and Underwriters' Laboratories. Compendiums of these specifications data for thermoplastic compounds include, for physical properties, such requirements as tensile strength, elongation, heat shock, heat distortion, flammability, low temperature stability, and resistance to solvents and to abrasion; and for electrical properties, such requirements as insulation resistance, dielectric strength, surface resistivity and, in case of high-frequency wires, power

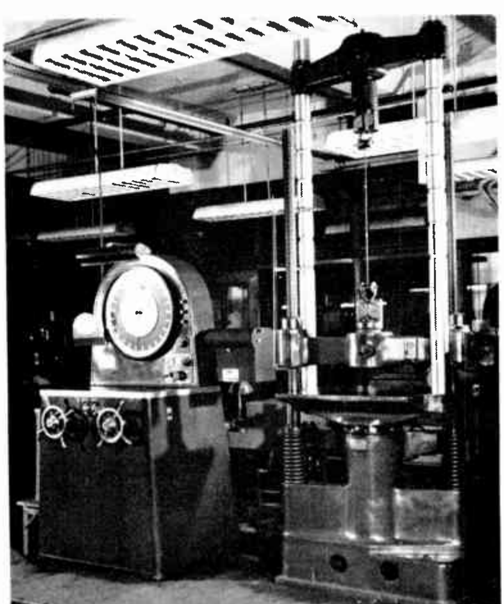


Figure 5. Tensile test of thermoplastic cable in universal testing machine

factor and dielectric constant. A discussion of the various important properties, physical and electrical, affecting characteristics of wire and cable, and of test methods employed for determining them is treated in paragraphs that follow.

PHYSICAL PROPERTIES

Tensile Strength and Elongation

Wire coverings must be able to withstand severe pulling and stretching. Since the elongation and tensile strength are indications of these properties, their measurement is important. A compound, for instance, with very high tensile strength and poor elongation is in general a poor material from the standpoint of wire and cable coverings. The test procedure for checking tensile strength and elongation, in general, is carried on in accordance with A.S.T.M. D-470 Methods of Testing Rubber Insulated Wire and Cable (Tentative). Figure 5 shows a specimen of thermoplastic insulated cable in course of tensile test.

Heat Shock Tests

Heat shock tests as covered by Western Union specifications comprise a "Strain Under Heat Test" and a "Strain After Heat Test." The former is intended to determine whether any strains have been set up in the extrusion process comparable to those which develop in the manufacture of glass articles when strains due to rapid cooling have not been relieved by proper annealing. A similar test is covered in both A.S.T.M. and Underwriters' Laboratories specifications for thermoplastic-insulated wire, although these tests provide for a higher temperature and a shorter subjection to the high heat. The strain after heat test is designed to reveal whether any impurities are present in the plasticizer, a condition which might, within a short time, cause cracking when the wire is bent sharply. This test was developed in our laboratories after some unfortunate cracking at sharp right-angle bends was experienced in the early days of our usage of this type of wire. The trouble was attributed to impurities in the plasticizer. Figure 6 shows the Geer type air-circulating oven used for making Western Union laboratory heat shock tests.

The *modus operandi* of the respective heat shock tests is similar in that the test specimens in both cases are exposed to a temperature of 212 degrees F in the oven for a period of 72 hours. In the case of the strain under heat test, the specimens are subjected to the high temperature conditions while wrapped around a mandrel of the diameter of the insulated wire. For the strain after heat test, however, straight specimens are hung in the oven and these are wrapped and unwrapped around the mandrel at room temperatures after a period of rest following conclusion of the heat cycle.

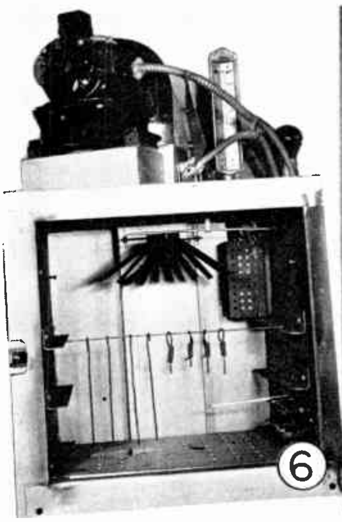
Although the heat shock tests described above have been in effect practically since the inception of our employment of thermoplastic insulation for wire and cable and still appear in most Western Union specifications for these materials, long experience with these compounds have brought into question the value of the strain under heat phase of the tests. The matter is now under study as to whether the strain after heat test, alone, the more severe of the two, may not be adequate not only to check for detrimental ingredients in the formulation but also to determine whether internal strains may have been set up in the extrusion process.

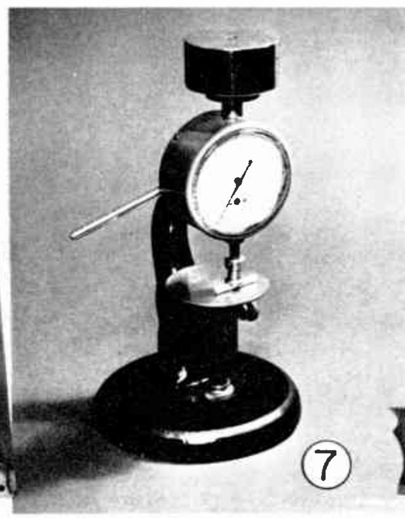
Heat Distortion Test

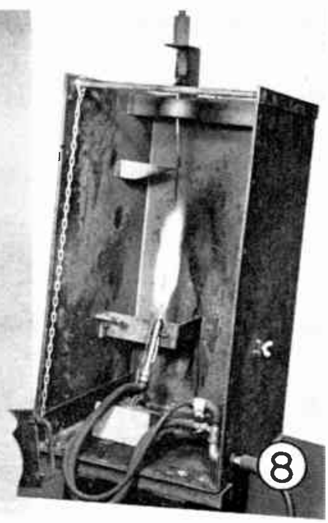
This test is variously described as "Heat Distortion Test," "Deformation Test" or "Flow Test." Both A.S.T.M. and Underwriters' Laboratories provide for such a test and specify subjection of a sample under a certain load, which varies with the gage of the conductor, to a temperature of 250 degrees F for one hour. The degree of distortion is determined by measuring the over-all diameters of the insulation before and after the heat test and calculating the decrease in the wall thickness of insulation. A Randall and Stickney gage (Figure 7) or equivalent is employed in making this test.

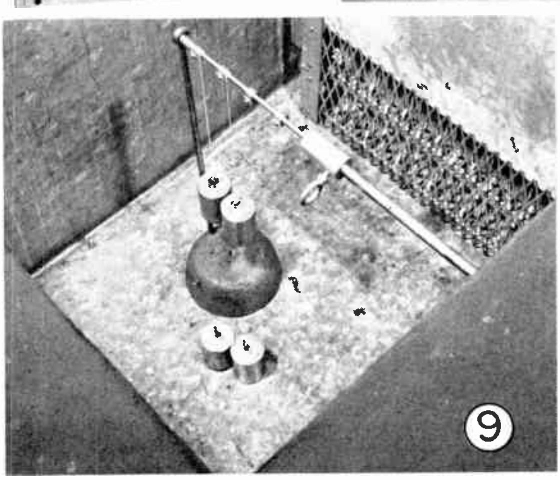
Flammability Test

The term flammability has been defined as the measure of the capacity of a material to support combustion. Polyvinyl chloride does not support combustion, but plasticizer used in the formulation may impair, to a degree, flame resistance of the compound. A flammability test is therefore included in our specifications for polyvinyl chloride insulated conductors. For No. 14 Awg wire and larger, Underwriters' Laboratories require a vertical type of flame test and A.S.T.M. calls for this type of test for No. 18 Awg and larger. Figure 8 shows a vertical flammability test in progress in the standard Underwriters' Laboratories flame test equipment. For small gage thin-wall insulated conductors, however, this test is too severe and a horizontal test is made instead. The procedure for this test followed by Western Union is that covered in R.T.M.A. Standard Gen-103, for Thermoplastic Hook-Up Wire (Class 1). Some discussion was held at a recent meeting of R.T.M.A. Committee on Radio Hook-Up Wire concerning possible discrepancies in results of flammability tests which might









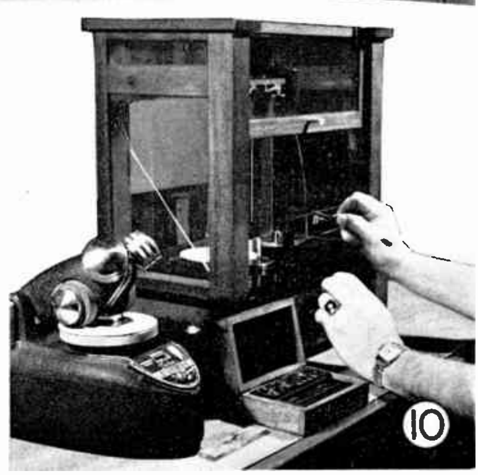


Figure 6. Set-up for heat shock test in Geer type air-circulating oven
Figure 7. Randall & Stickney gage with test specimen in place
Figure 8. Vertical flame test of thermoplastic insulated wire
Figure 9. Set-up for cold test of thermoplastic insulated wire in sub-zero constant temperature cabinet
Figure 10. Abrasion resistance test of thermoplastic insulating compound

result from differences in flame temperature of the igniting agent. Tests were subsequently carried on employing natural and "bottled" propane gas which produce flame temperatures about 400 degrees F apart, but it was found that the difference in flame temperatures does not materially affect the test results.

The measurement of flammability is still a controversial problem in the plastics industry and the methods used for testing this property are inadequate for purposes of comparison. Some progress has been made in quantitative determinations of flammability of thermosetting plastics but nothing has yet been developed for such tests of thermoplastic materials.

Cold Test

Low temperature tests are made in the Western Union laboratories, employing for the purpose a sub-zero constant temperature cabinet. Western Union specifications for inside wire provide for subjection of a sample of the wire to winding around a ¼-inch mandrel after having been subjected to a temperature of 14 degrees F for a 2-hour period, while specifications for outside wire require a test made in the same manner, but at an ambient temperature of 4 degrees F. No cracking of the insulation as a result of this treatment is permissible. In Western Union laboratory work, however, thermoplastic compounds have been tested which withstood temperatures as low as —80 degrees F. All tests made by this method are carried on under uniform temperature without removal of the specimen from the cold chamber. A picture showing samples of wire ready for tests in the sub-zero constant temperature cabinet is shown in Figure 9.

Solvent Tests

Western Union tests for resistance to solvents are usually confined to oil and to carbon tetrachloride with which solvents the insulation may come in contact. Jan-C-76 specifications cover tests employing a somewhat wider range of solvents, including salt water, gasoline, motor oil, ethylene glycol, and commercial methyl or ethyl alcohol.

Abrasion Resistance

Abrasion resistance tests are not commonly required in current specifications for thermoplastic insulated conductors. A requirement for such a test, however, appears in Jan-C-76 specifications for WL Cable, intended for general purpose applications. This test requires use of a special mandrel type machine. Military Specifications W-5086 for Copper Aircraft Wire specify abrasion test requirements to be made with a type of abrasion tester covered by Military Specifications Mil T-5438. Abrasion tests are made in the laboratory at present on flat specimens employing the Taber Abraser (Figure 10) and serve to give an indication of that property. The test procedure is that outlined in method 1091.1 in Federal Specifications L-P-406-b. The construction of a machine suitable for measurement of abrasion resistance in the form of wire and cable coverings, however, is now under study for the laboratory work. An abrasion tester designed especially for checking that property of wire and cable is presently in use at the Frankford Arsenal, Philadelphia, Pa., and a paper describing it was read at a recent symposium on wire and cable sponsored by the Coles Signal Laboratory, Fort Monmouth, N. J.

ELECTRICAL REQUIREMENTS

Insulation Resistance

Insulation resistance where small currents are used as in telegraph circuits must be of a high value, since leakage losses may seriously impair operation of the circuit.

This property is usually measured on a length immersed in water under impress of a d-c voltage. The water temperature should be within the limits 46 and 80 degrees F, and the reading is usually corrected to 60 degrees F. The insulation resistance is inversely proportional to the area under test and directly proportional to the thickness. For example, if an insulating material is placed between two metallic electrodes, insulation may be found to be 50 megohms, but if the area of the specimen were to be increased ten times, the insulation resistance will be only 5 megohms; if, however, the thickness of the material is doubled, the insulation resistance will be 100 megohms. The inverse proportionality law affecting area explains the higher insulation resistance values which always apply for shorter as against longer lengths of insulated wire. Figure 11 shows a galvanometer mounted on a Julius suspension with other equipment for making insulation resistance tests.

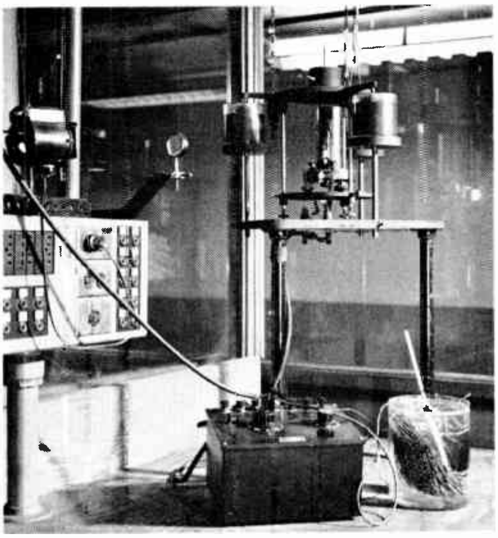


Figure 11. Test set with galvanometer mounted on Julius suspension and insulation resistance test set

Dielectric Strength

A.S.T.M. D-149 Standard Methods of Test for Dielectric Strength of Electrical Insulating Materials defines dielectric strength of an insulating material as the maximum potential gradient that the material can withstand without rupture. The dielectric strength tests are made ordinarily with alternating current potential since the voltage required is in general higher than can be conveniently obtained from a d-c source. The dielectric strength obtained with a direct current has been established empirically as two to three times that obtained with an alternating current. Insulated Power Cable Engineers Association's Standard S-19-81, General Specifications for Wire and Cable with Rubber, Rubber-like and Thermoplastic Insulations (Second Edition, February 1951) specify that *the ratio of d-c to the equivalent RMS a-c voltage shall be not less than 2.2 for non-ozone resistant and not less than 3.0 for ozone resistant compounds.*

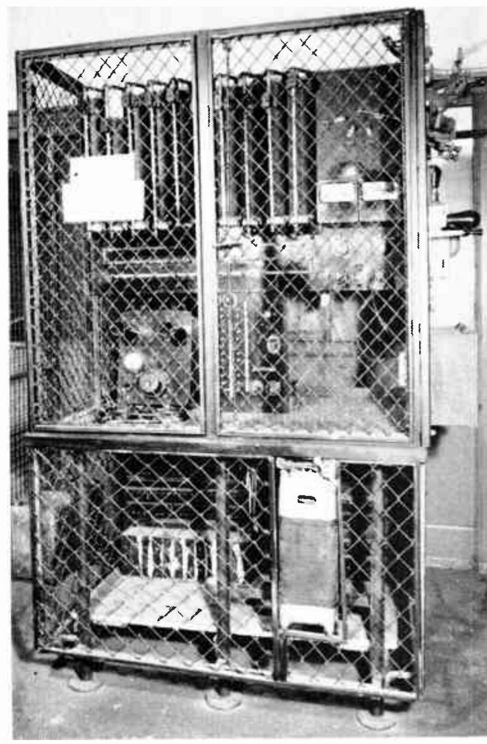


Figure 12. High-voltage testing apparatus

The dielectric strength varies with the thickness of the specimens to be tested, decreasing as the specimen thickness increases. It is generally expressed as volts per mil. Figure 12 shows laboratory equipment for making voltage breakdown tests on wire insulation.

Power Factor

Alternating voltage across any dielectric material produces a current of magnitude dependent on conductance or leakance of the insulation and on the capacitance. If the insulation permits absorption of cur-

W. E. Burke graduated from Pratt Institute and studied at Columbia University and at Brooklyn Polytechnic Institute. After employment as a draftsman including service with Western Electric he joined Western Union in that capacity in 1912. Two years later he was assigned to work in preparation of specifications for outside materials and tools. In 1921 when Western Union organized its own inspection department, he was made supervisor of "approved sample" or quality control inspection and held that post for fifteen years. He was next assigned to work on wire and cable investigations and on studies of protective coatings in the Lines Engineer's Division and in 1943 was transferred to the Physical and Chemical Research Division. He has always been identified with the Company's American Society for Testing Materials activities and in recent years has taken an active interest in the work of Radio Television Manufacturers' Association's Committee on Thermoplastic Hook-Up Wire.

rent an actual rise may occur in the temperature of the insulation. The energy thus lost in the dielectric is measured by the power factor. The technical definition of power factor given in American Society for Testing Materials D-150, Tentative Method of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials, is as follows: *The dielectric power factor of a material is the cosine of the dielectric phase angle or the sine of the dielectric loss angle.* It is important for most uses of insulating materials and particularly for high frequency applications that these losses be of a low order.

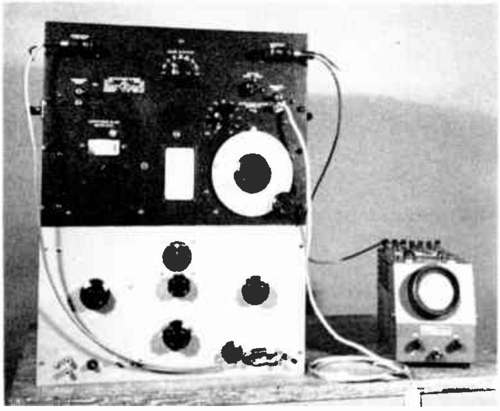


Figure 13. Capacitance bridge, oscillator and oscilloscope used for making power factor and dielectric constant determinations

In communication cables, particularly, a low power factor is essential to assure maximum transmission efficiency.

Dielectric Constant

Insulating materials vary in their ability to store energy in themselves. A gage of the stored electrostatic energy in the insulating materials is known as the dielectric constant or specific inductive capacity. This may be defined as the ratio of the electric capacitance of a sheet insulating specimen fitted with metal foil electrodes and the capacitance with the same electrodes having the specimen replaced by air. For communication lines it is desirable that the capacity for storing energy be as low as possible. Hence, a compound with low dielectric constant offers advantages, and is indeed requisite for high-frequency circuits. A capacitance bridge, oscillator and oscilloscope used in our laboratory in making power factor and dielectric constant determinations are shown in Figure 13.

Surface Resistivity

Surface resistance is sometimes a troublesome factor. Some materials are of a nature to allow a continuous conductive film to form on the surface under conditions of high relative humidity; others are such that the moisture, if formed, breaks into small globules and does not seriously affect surface resistance. A test for this property is unnecessary for materials like the fluorocarbons and most vinyls which are known to have non-wetting properties, but may be important in particular for textile covered conductors which sometimes have a wicking action.

Conclusions

Each of the thermoplastic materials has its advantages as well as its limitations for wire and cable insulation and jackets. When used with appreciation of their good and bad properties and with intelligent selection, they should provide coverings of longer life and greater serviceability than materials available for this purpose in the past. With the research staffs of competitive thermoplastic manufacturers continually seeking to bring out improved compounds, the development of even better formulations is practically assured.

Thanks and credit are extended to Bakelite Company, B. F. Goodrich Chemical Company, and General Cable Corporation for helpful suggestions.

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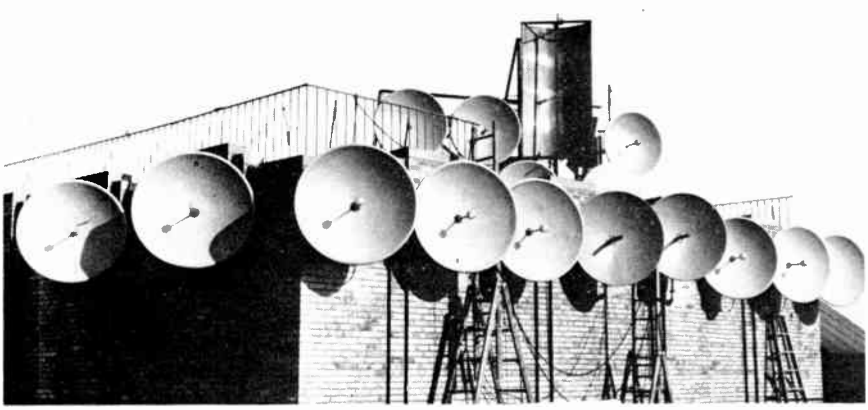
MICROWAVE ANTENNA ARRAY FOR TELEGRAPHY



Here are even more microwave antennas than were used temporarily on International Amphitheatre, Chicago, for broadcasting and television at the 1952 political conventions.

This experimental array was mounted on the Western Union 24-story building in New York City in 1948 to beam radio test and message signals inland. In addition to the fifteen 4-foot diameter parabolic "dish" reflectors which either concentrate emitted microwaves into radio beams or gather incoming impulses, an experimental parabolic "cylindrical" reflector appears in the upper group. The cylinder was made of copper but most of the "dishes" were spun from aluminum.

Today this rooftop carries eight such antennas for regular traffic plus two experimental reflectors. Four diversity antennas not shown are mounted at a lower level. Western Union pioneered commercial microwave communications.

Notes on Microwave Propagation

J. Z. MILLAR and L. A. BYAM, JR.

THESE NOTES are intended as a brief discussion of the fading which occurred during an extended microwave propagation experiment, operated at a frequency of 4000 mc. Several similar tests have been conducted in recent years and have yielded considerable information concerning the behavior of microwave signals under the influence of varying atmospheric conditions. Most of this information is available in the literature, having appeared in articles published by Durkee,[1] Friis,[2] Millar and Byam,[3] Kiely and Carter,[4] Crawford and Jakes,[5] and by others.

Although the test under consideration was conducted under conditions very much similar to earlier tests, there were two important differences. First, the present test included spaced diversity reception whereas in earlier tests diversity reception was not employed. Simultaneous recordings of both main and diversity signals afforded means of fade-by-fade comparison and provided data for a general analysis in determining the effectiveness of diversity action. Secondly, earlier tests were made with an r-f power output in the neighborhood of 0.1 watt at 4000 mc, whereas in this more recent test a c-w type magnetron delivered approximately 10 watts at the same frequency. The hundred-fold increase in output power added 20 db to the depth of the measurable fade.

Test Conditions

A Raytheon Type QK151 magnetron, serving as the source of r-f power, delivered approximately 10 watts of unmodulated carrier at a frequency of 4000 mc into the transmitting antenna situated atop the Western Union Building at New York. At Neshanic, New Jersey, separate simultaneous recordings were taken of the received signal as appearing on the main and on the diversity receiving systems. Recorders were of the motor-driven type, operated from the same 60-cycle a-c power source, and were synchronized. The test path involved will be recognized as one used in a prior propagation test. It is situated almost entirely over land and is approximately 42 miles in length. A profile picture of this path appears in Figure 1.

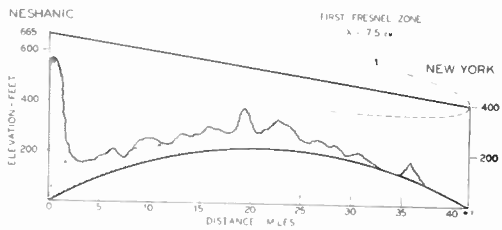


Figure 1

Since the profile was constructed on the basis of a four-thirds earth's radius, the transmission path was shown as following a straight line to represent "standard" or "normal" conditions of propagation. The transmitting and receiving antennas were of the dipole type, coaxial fed, and the associated reflectors were conventional parabolic surfaces, 48 inches in diameter. The diversity receiving antenna was situated directly below the main receiving antenna, and separated from it by a vertical distance of 31 feet, center to center. Finally, recordings were taken for a period of roughly 14 months, beginning on January 9, 1950.

Carrier-to-Noise Ratio

An exact determination of the carrier-to-noise ratio requires, among other things, accurate information as to the noise figure of the receiver used. When the absolute noise of a receiver is not known, it is convenient and usually sufficiently accurate to assume a representative noise factor such as fifty times thermal or 17 db above thermal. Modern

A paper presented before the National Convention of the Institute of Radio Engineers in New York, N. Y., March 1953.

microwave receiver design has improved noise factors to within twenty times thermal. In the present case, the factor of fifty was used as a concession to earlier design considerations. It is interesting to note the manner in which other factors influence the carrier-to-noise ratio, as indicated by the relationship shown below:

$$C/N = 2.42 \times 10^{-2} \times \frac{D^4}{L^2} \times f^2 \times \frac{P_t}{B}, \text{ where}$$

D is diameter of reflector in feet
L is path length in miles.
f is frequency in mc.
P_t is transmitter power in watts.
B is receiver bandwidth in mc.
C/N is carrier-to-noise ratio.

To obtain C/N in terms of decibels, the following form is used:

$$C/N = -16 + 40 \log D + 20 \log f + 10 \log P_t - 20 \log L - 10 \log B.$$

For the conditions of the test, as outlined, and with the further assumption of 4 mc as representing the receiver bandwidth, a carrier-to-noise ratio of 51 db obtains.

Analysis of Data

Although very nearly two miles (representing 10,107 hours) of signal recording strip was examined, attention was directed primarily to those fades which dropped 15 db or more from the normal signal level. (As in the previous test, the normal signal represents the mean signal level for periods during which fading was absent or negligible, i.e., periods when transmission was stable.) For each such fade, the essential data were extracted and tabulated, including information with respect to the corresponding level of the diversity (or main) signal.

Initially, in the interests of operational considerations, these data were assembled and represented in a form, Figure 2, intended to reveal the general structure of the fading occurring during the test. The two upper curves of Figure 2 portray the generally regular manner in which the number of fades decreases with depth. For the range of signal levels considered, there were many more fades on the main than on the diversity, the difference varying by a factor of roughly two at the −15 db level to roughly nine at the −35 db level.

The two lower curves shown in Figure 2 represent the average length in minutes of all fades falling below the abscissa level considered. It will be observed that the ordinate scale associated with these two curves appears at the right-hand side of the chart. To illustrate, the average duration of fades falling below the signal level of −20 db was 4.8 minutes with respect to the main receiver and 2.6 minutes with respect to the diversity. Although some degree of similarity is suggested by the manner in which the length of fade generally decreases with increasing depth of fade in both main and diversity antennas, the marked difference between these two curves requires explanation. About midnight on February 1, 1951, the diversity signal fell to slightly more than 35 db below normal and remained at that level for well over an hour. At the same time, the main signal also faded but with much less depth and for a shorter duration. Were it not for this one fade, the two curves would have exhibited a marked similarity.

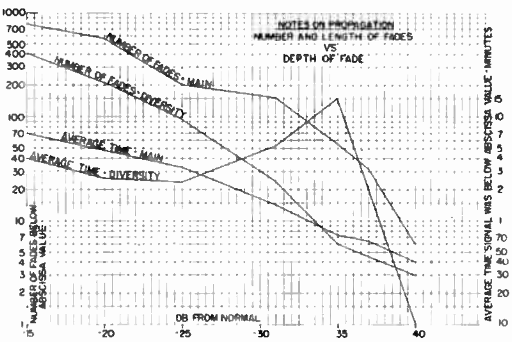


Figure 2

Ideally, a microwave radio system is engineered to have a signal-to-noise ratio which includes, among other things, a sufficient fading-allowance margin to insure the degree of continuity dictated by service requirements. For a smaller signal-to-noise ratio, deterioration of service would obtain; a higher value would be considered as extravagant. Practical considerations therefore require reliable information to be available which will permit translating service demands in terms of fading-allowance margin. For this purpose, distribution curves of instantaneous signal strength, together with associated curves representing distribution of fade length, are helpful, particularly if such curves represent data taken over a long period of time. Curves A and B of Figure 3 represent distribution of instantaneous signal strength for the main and diversity respectively based on the data taken from the test. Similarly, the curves appearing in Figures 4 and 5 represent distributions of fade length.

For purposes of comparison, additional curves are shown in Figure 3, as identified thereon. Curves D and E are based on data appearing in the *Bell System Technical Journal* of January 1952 in a paper written by Messrs. Crawford and Jakes.[5] The pronounced spread between the main and diversity curves is noteworthy and indicates that fading was less severe on the diversity than on the main. Generally, the diversity signal during periods of moderate fading was found to be three or four dbs higher than the main, a good example of which may be found in Figure 8. This effect is attributable to the geometry of the system, and where depth of fading is a determining factor, forms a basis for locating antennas somewhat lower than at the Fresnel maximum. In any event, the marked difference in fading effects as reflected by these curves, A and B in Figure 3, is remarkable in that it was occasioned entirely by the 31-foot vertical separation between the main and diversity receiving antennas. The importance attached to careful probing of proposed tower sites will thus be understood. The effect of the infrequent case of fading mentioned in discussing Figure 2 is again manifested in the shape of that portion of Curve B, Figure 3, lying below the 0.04 percent level. Again, were it not for this one fade, Curve B would have appeared strikingly similar to Curve A from the 0.04 percent level on downwards, as was found by tentative plotting of data which excluded the fade in question. Other curves, C, D, and E, are included in Figure 3 for purposes of comparison. A comparison of Curve D with that of E would seem to indicate that the effect of path length is virtually obscured under the influence of other considerations, such as, for example, path clearance.

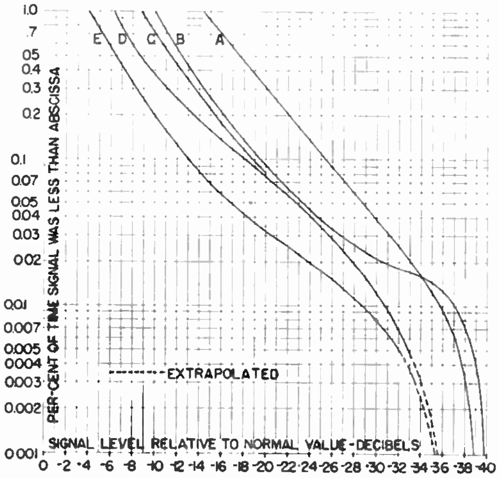


Figure 3

LEGEND — FIGURE 3

	CURVE	SPONSOR	TEST PATH	PATH LENGTH	1st FRESNEL CLEARANCE	PERIOD
(Main)	A	W. U.	N. Y. — Neshanic	41.7 Mi.	No	Jan. 9. 1950—Mar. 20, 1951
(Diversity)	B	W. U.	N. Y. — Neshanic	41.7 Mi.	No	
	C	W. U.	N. Y. — Neshanic	41.7 Mi.	No	Jan. 1—Dec. 31, 1947
	D	Bell System	Crawford Hill — Southard Hill	17.0 Mi.	Barely	April—Nov., incl. 1947 1948
	E	Bell System	Crawford Hill — Murray Hill	22.8 Mi.	Yes	April—Nov., incl. 1949 1950

These distribution curves may also be considered as fading probability curves and thus used to determine the probability of a fade having a duration greater than zero minutes below the level considered, i.e., the probability of a fade occurring below that level. For example, according to Curve B, Figure 3, the probability that a fade will occur having a depth greater than 20 db below normal is 0.0009; the probability of a fade falling more than 32 db below normal is 0.00018.

At this point, it would appear logical to consider information bearing on the relative time duration of fades. For this purpose, the charts shown as Figures 4 and 5 were prepared, based on data obtained from the experiment. The curves appearing in Figure 4 are distribution curves of fade length for fades occurring on the main receiver. Distribution curves for the diversity are shown in Figure 5. With respect to Figure 4, no explanation could be found for the coincidence of the —20 and —25 db curves. When plotted, the points for these two curves virtually coincided leaving no alternative to representation by a single curve. Data for the —40 curve were considered insufficient properly to represent a significant distribution at this level and for that reason the curve is labeled "estimated". The straight-line distributions obtaining as shown in Figure 5 (using logarithmic probability paper) are considered noteworthy.

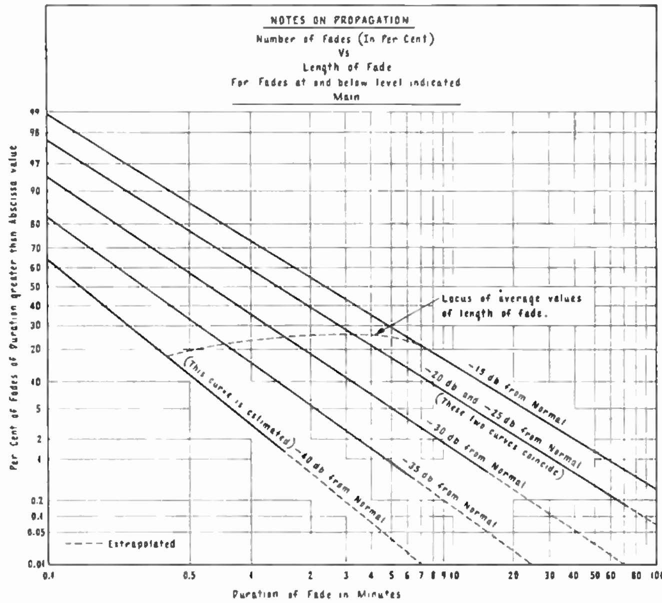


Figure 4

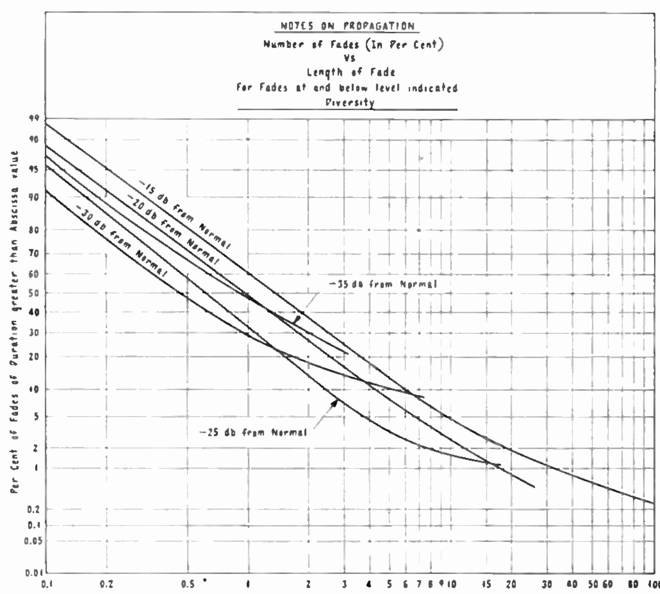


Figure 5

The manner in which the distribution curves of Figures 4 and 5 supplement those of Figure 3 is best explained by example. Again selecting the diversity curves, assume the occurrence of a fade below —20 db. From the —20 db curve of Figure 5 the probability that this fade will remain below —20 db for more than 2½ minutes is 0.20. But, the probability of a fade falling below —20 is 0.0009 as determined from the earlier example using Curve B of Figure 3. Hence the probability of a fade remaining below —20 db for more than 2½ minutes is

0.0009 × 0.20 or 0.00018. In a like manner similar information may be obtained for various other levels and time intervals within the range of the curves. Such information is helpful in that it provides a means of determining fading-allowance margin in terms of service requirements. As a simple illustration, assuming that a particular service requires that the probability of an interruption of more than ½ minute shall not exceed 0.001, the fading-allowance margin is found to be 17 db.

Diversity Action

As stated earlier, attention was directed primarily to those fades with excursions of 15 db or more below normal. Usually when such a fade occurred on the main it was accompanied by a diversity fade of somewhat the same general pattern although the diversity fade was generally less severe. This characteristic of similarity is illustrated in Figure 8 and was manifest on 79.9 percent of the total number of occasions that the main faded below −15 db. Of the 79.9 percent occasions on which similarity was exhibited, the diversity fade started downward at approximately the same instant as the main on 66.4 percent occasions; the diversity fade preceded the main on 9.6 percent occasions and the diversity fade followed the main on the remaining 3.9 percent occasions. For 20.1 percent of the total number of occasions that the main faded below −15 db there was no similarity in the action of the main and diversity signals, i.e., the diversity signal faded upward or in opposition to the main, as illustrated in Figures 9 and 10, or was constant or otherwise independent of the main fade, as illustrated in Figure 11. In passing, it will be noted that the number of times a diversity fade preceded the corresponding main fade exceeded the number of times a diversity fade followed the corresponding main fade by a ratio of 2½ to 1.

On 80.7 percent of the total number of occasions that the main faded below −15 db the diversity did not fade below −15 db; on 38.3 percent of the total number of occasions that the diversity faded below −15 db the main did not fade below −15 db. Stated in a different way, 19.3 percent of the main fades below −15 db occurred simultaneously with 61.7 percent of the diversity fades below −15 db. During periods of simultaneous fading below −15 db, one main fade "mixed" on the average with 1.7 diversity fades. Simultaneous fading did not occur below the level of roughly −38 db. Thus, in terms of the number of fades, diversity action may be considered as 80.7 percent effective with respect to the −15 db reference level and 100 percent effective with respect to the −38 db reference level. The manner in which the effectiveness of diversity action varied with signal level is shown by the curve appearing in Figure 6.

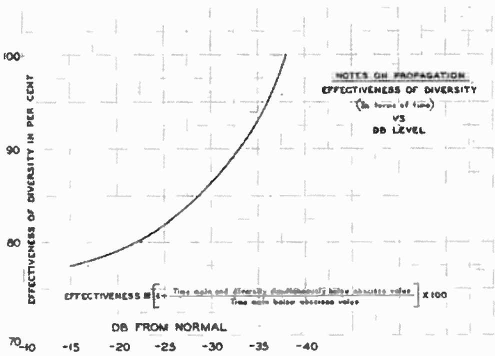


Figure 6

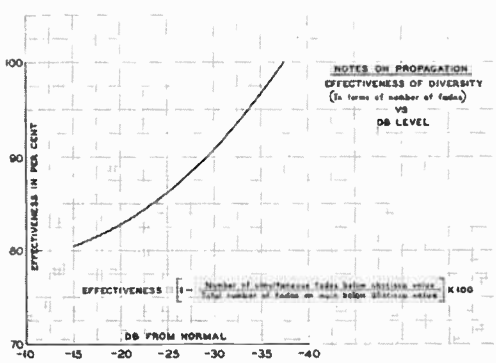


Figure 7

In the preceding paragraph consideration was given to the relative number of main and diversity fades below −15 db for both simultaneous and nonsimultaneous fading conditions; nothing was said with respect to the time duration of fading under these two conditions. During nonsimultaneous fading below —15 db the average length of the main fade was 4.3 minutes; the average length of the diversity fade was 2.6 minutes. During simultaneous fading, however, the average length of the main fade was 17.7 minutes and that of the diversity 4.8 minutes.

During 77.5 percent of the time the main signal was below —15 db the diversity signal remained above —15 db; during 25.0 percent of the time the diversity signal was below —15 db the main signal remained above —15 db. Stated in another way, simultaneous fading below —15 db occurred for 22.5 percent of the time the main was below —15 db or 75.0 percent of the time the diversity was below —15 db. Simultaneous fading did not occur below roughly —38 db. Thus, in terms of time duration of nonsimultaneous fading, the effectiveness of diversity action may be considered to be 77.5 percent at the —15 db reference level and 100 percent at the —38 db reference level. For other levels, the effectiveness of diversity action may be determined from the curve appearing in Figure 7.

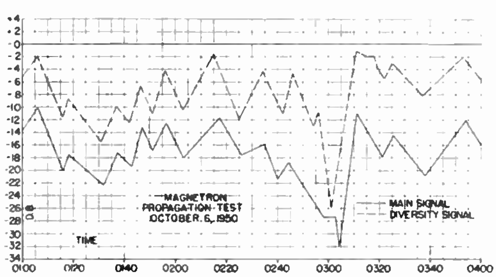


Figure 8

In concluding the discussion on diversity action, consideration will be given to the mechanics of correlation in analyzing the relationship of simultaneous variations in the main and diversity signals under two general but entirely different conditions of fading. These two conditions were arbitrarily chosen.

The first condition will be referred to as moderate fading and includes only those fades whose minima ranged roughly from —10 db to —20 db. Such fades were found generally to be of the comparatively slow type of fade and during which similarity of variations in the main and diversity signals was observed as illustrated in Figure 8. From a sample taken of such fades, the maximum depth was tabulated for each fade together with the corresponding value of the diversity (or main) signal at the same instant. Under this condition of fading a correlation coefficient of +0.69 was obtained. Thus, a fairly close relationship is indicated and it may be concluded that the diversity was not particularly helpful under the condition defined above as moderate fading.

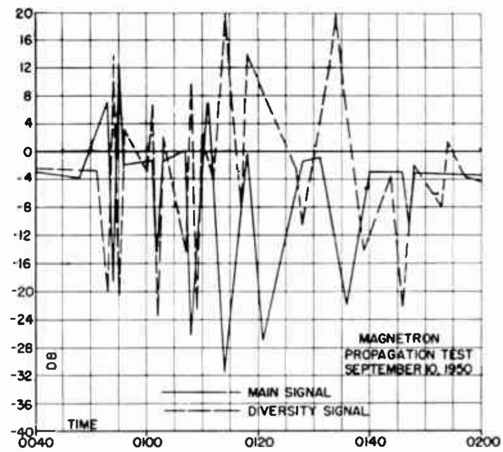


Figure 9

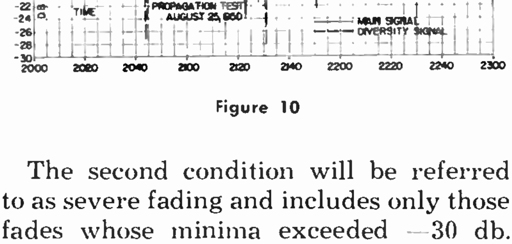


Figure 10

The second condition will be referred to as severe fading and includes only those fades whose minima exceeded —30 db. Such fades were found generally to be of the comparatively rapid type of fade, characteristic of wave interference. In this case the sample consisted of all fades falling more than —30 db and for each such fade the maximum depth was tabulated together with the corresponding value of the diversity (or main) signal at the same instant. Under this condition of fading a correlation coefficient of —0.36 was obtained. Thus, it may be concluded that the diversity was decidedly helpful under severe fading conditions as defined.

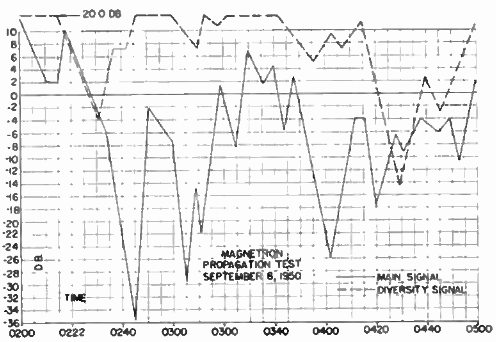


Figure 11

General Comments

The foregoing, although by no means an exhaustive analysis of the data obtained from the experiment, furnishes specific quantitative measurements which portray the essential aspects of the fading encountered during the test. Since the analysis included data on fading at comparatively much greater depth, the results supplement those of earlier propagation tests in which the same path was used.

Although the test extended over a long period of time, it is not intended that the results obtained may be applied to a propagation path other than the one used in the experiment. For an overland path of approximately the same length and under the same conditions of clearance, however, the results may be useful in arriving at a general prediction of fading effects.

The general similarity in form exhibited by the distribution curves would seem to be worthy of notice.

Acknowledgement

Under the guiding hand of Mr. H. M. Richardson, several members of the Radio Division contributed their talents and energy at one time or another in setting up and operating the test. Most of the work involved in the preparation of the fade charts was done by Mr. E. G. Nelson. Much of the preliminary statistical work was also done by him and by Mr. J. A. Mitchell.

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J. Z. Millar has been with Western Union since his graduation from the University of Illinois in 1923, starting as an engineering apprentice in the Washington, D. C., office. In 1926 he was transferred to the Water Mill Laboratory, where electronics was his field of work. After specializing on short wave equipment and audio frequency apparatus for 15 years, Mr. Millar was called to active duty with the Signal Corps in which he attained the rank of Colonel. He served as Member and Director of the Signal Corps Board in Fort Monmouth, N. J., from March 1941 to April 1944, and was then assigned as Signal Officer of the Normandy Base section and as Signal Officer, Loire Section, European Theatre. On February 15, 1945, he returned to Western Union and was appointed Radio Research Engineer. In that position he organized the Radio Research Division which handles all radio research projects. Mr. Millar was appointed Director of Research in August 1949. He is a Senior Member of IRE and a Member of AIEE.

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L. A. Byam, Jr., Assistant Radio Research Engineer, served a year as Morse operator with Western Union and three years as a radio operator with the Radiomarine Corporation before entering the University of Delaware. He was graduated in 1932 with the degree of B.E.E. and then enrolled in a special course of study at M.I.T., completing it in 1933. Mr. Byam rejoined Western Union in 1933; in January 1937 he was appointed Division Commercial Manager in charge of Operation, and served in that capacity until May 1941 when he was called to active service with the Navy. During the war he was engaged in radar installation and maintenance under the direction of the Bureau of Ships. Mr. Byam resumed service with the Company in January 1946 and engaged in radio research with the Development and Research Department. He is a member of IRE, Phi Kappa Phi and Tau Delta Pi, and a Professional Engineer in the State of New York.

H. H. HAGLUND

ABOUT 2600 nautical miles almost due east of New York City on the Island of Fayal in the Azores is the little town of Horta. Located 38.5 degrees north latitude and 28.5 degrees west longitude, this otherwise typical sleepy Portuguese insular village holds a unique position in the world of communications. More ocean cables now land here than almost any other place in the world and it is the only spot on the globe from which cables radiate roughly north, south, east and west.

The telegraph station also has a unique distinction. Cables owned by British, French, Italian, (and formerly German), and two American companies all terminate in the same building with operating rooms so laid out that messages can be passed through *guichets* or windows from one to the other.

In close proximity to the cable station are the staff quarters of the operating companies: Western Union, the Commercial Cable Company, Cable and Wireless, and the German Company.

Each group includes one- or two-family houses for Directors, Superintendents, Electricians and other married staff, and a staff house for single men, as well as certain recreational facilities such as tennis courts. Western Union has, in addition, a small hospital building. The German Company's houses were vacated at the beginning of the last war and are now either vacant or rented out to local families.

Mild but Humid Climate

The climate in the Azores is mild. Winter temperatures rarely go below 45 degrees F. and in summertime 86 degrees F. is about the maximum, although the high humidity often present may make this temperature somewhat oppressive. There is a definite rainy season.

Although of volcanic origin, the islands are fertile. Fayal has quite a dairy industry and some very fine cheese is made on the island. Horta is known for its flower gardens, and hedges of hydrangea cover most of the stone walls which bound the farms. During flowering season these blossoming hedges give the landscape a wonderful touch of color.

Coins discovered on the nearby island of Corvo seem to prove that the Azores were known to the Carthaginians, and the Arabian geographers—Edrise in the 12th century and Ibn-al-Wardi in the 14th — describe, in addition to the Canary Islands, nine islands in the Western Ocean which probably were the Azores. They were first distinctly marked on a map in 1351. Gonzalo Velho Cabral took possession of Santa Maria in 1432, St. Michaels in 1444 and the other islands, including Fayal, in 1457. Fayal was presented by Alphonso V to his Aunt Isabella, the Duchess of Burgundy, which accounts for the fact that many of the early settlers were Flemish.

Operations buildings at Horta as they appeared early in 1928 shortly after completion of the new structure in foreground.

Cable Activities Start

Submarine cable history in Horta began in 1893 when a cable was laid to Ponta Delgada on St. Michaels, which in turn was connected with Carcavellos on the Portuguese mainland, over 800 miles eastward.

In 1900 three cables were laid into Horta, one by the American Commercial Cable Company from Canso, Nova Scotia, one by the British from Porthcurno on the southwestern tip of England, and one by the Deutsch - Atlantische - Telegraphen - Gesellschaft, from Horta to New York. The next year Commercial Cable Company added a cable from Horta to Waterville, Ireland, thus giving them a route New York to London via Canso, Horta, Waterville, and Bristol, England.

One more cable was brought into Horta in 1903 when the German company laid a cable from Horta to Emden, Germany, thus completing their New York-Emden route, and in 1904 still another cable was laid, this one into Halifax, Nova Scotia, as a connection for the British company's Porthcurno-Emden section.

The pattern of the communications crossroads thus began developing. In 1906 a north-south route was added when the British laid a Porthcurno-Horta-St. Vincent line to connect England via Ascension

Residences of Western Union Director (right), Superintendent and Chief Electrician (left), recreation building (beside tennis courts), and two-family dwellings and staff house (center).

Islands with South America and South Africa.

During World War I, the DAT cable was cut by the Western Allies, its east end diverted into Brest, and its operation taken over by the French Cable Company. After the armistice of World War I, communication demands rose abruptly and more cables were laid via Horta. At that time an interesting technical development also began.

All cables into Horta up to then were of a type that had been more or less standardized. Speeds were low. With the best equipment known at that time all were operating at 200 letters or less per minute each way, duplexed. The code used was so-called "cable recorder code", a modified Morse code read by sight instead of by sound. "Dots" and "dashes" are of equal length but opposite polarity related to ground. When written in ink on a moving paper tape, the dots are above the center and the dashes below the center line of the signals.

Faster Operation Desired

Both Western Union and Commercial Cable Company were planning new cables; Commercial Cable Company to England and Western Union, in cooperation with Italcable, into Malaga, Spain, and Rome and, in cooperation with DAT, into Germany. Both companies wanted greater speed. Two methods for increasing the cable speeds were known. The conventional one called for increasing the size of the cable thereby decreasing the product of its capacitance and resistance — the so-called KR of the cable — which determines the signaling speed. The second one, an untried method for ocean cables, provided for reducing the electrical effect of the KR by means of loading.

Wooden wheeled ox-carts like large basket-weave chariots moved many tons of rocks, earth and building materials for the Horta station.

Loading was well known in the telephone plant. Loading coils were common on all long distance telephone circuits of that time and telephone cables over narrow bodies of water had been loaded by both the "lump" and the "continuously loaded" methods. Addition of inductance coils at properly spaced intervals produced lump loading while continuous loading was obtained by wrapping the conductor with a magnetic material over its entire length. Although silicon steel which had the best permeability of any material known at that time was satisfactory for continuous loading of telephone cables, it was not suitable for cables to be used at telegraph frequencies. If a wrapping of this material were applied which was theoretically sufficient properly to load the cable, it would increase the cable conductor diameter and consequently its capacity but would not materially affect its resistance, with the practical result that the product of resistance and capacitance (KR) would be increased rather than decreased, thus totally offsetting the gain obtained by the added inductance.

In the very early 1920's, however, Dr. G. V. Elmen of the Bell Telephone Laboratories produced a new nickel iron alloy named "Permalloy" which at low flux densities had many times greater permeability than silicon steel, and it was quickly pointed out that this material might make the loading of long submarine cables practical. But there were constructional difficulties yet to be solved.

Commercial Cable Company engineers decided to follow tried methods and laid their new cable, nicknamed the Jumbo, from New York to London via Canso, Horta, Waterville, and Bristol in 1923. The weight of the copper conductor in the Horta-Waterville section is 1100 lbs. per nautical mile as against 170 lbs. in the corresponding 1901 section. The design gave a

Power house and harborside locality below operations buildings. Across the bay, the precipitous cliffs are typical of the island seacoast.

Guia Peninsula, in the middle distance, where are located three submarine cable hut terminals, with Pico Island in clouds in the background.

KR of 0.66 compared with 3.6 for the earlier section, a tremendous improvement, and plans called for operation at 500 letters per minute, duplex, cable code, to make this the world's then fastest long submarine cable.

Western Union Tries Loading

Western Union engineers were inclined to take advantage of the new technique—loading. In cooperation with Bell Telephone Laboratories an experiment was carried out with a 120-mile section of Permalloy loaded cable laid off the island of Bermuda. As one of the characteristics of Permalloy is that when subjected to mechanical strain its permeability decreases, it was feared that when the cable was immersed in deep water the effective loading might be greatly decreased. But the Bermuda tests were encouraging and Western Union decided to assume the risks involved. A New York-Horta loaded cable was laid in 1924.

Tests on the completely laid cable showed that although in water as deep as 2925 fathoms, where the pressure on the cable is 7800 lbs. per square inch, the Permalloy loading, protected by a viscous fluid to equalize the stresses, was not damaged. The speed of the cable was to be 1500 letters per minute in one direction and it was realized that it would not be possible to balance the cable for duplex operation.

The high speed at which the cable would be worked and the fact that it could not be duplexed brought additional problems to the engineers. Conventional cable apparatus, such as Heurtley magnifiers and drum relays would not work at the higher speed, and since the cable was eventually to be linked with a new DAT cable of similar design, it was imperative that some means be provided so that messages could be sent both east and west without undue delay in either direction. The speed was also too high for a cable code operator either to transmit or to record at the full cable speed, and modern trends indicated that ultimately printing methods must be applied to the cables. All these factors led to the development and use of vacuum tube signal shaping amplifiers, and a 5-channel multiplex printing system with facilities for automatically reversing the direction of operation at intervals of from one to three minutes in each direction. Facilities were also provided for unequal periods to fit a directional load, as for instance two minutes eastward and one minute westward and vice versa.

In 1924 Italcable laid its network of cables, one of which terminated at Horta with the other end at Malaga in Spain, where it was connected with another section to Anzio near Rome. The DAT laid their 5-channel loaded cable between Borkum and Horta in 1926; four channels of this were promptly connected to New York through the multiplex equipment already mentioned. The final speed between New York and the Emden terminal was set at 1565 letters per minute—the highest speed at which any transatlantic cable had ever operated.

During World War II the DAT again lost their cable properties. The cable was cut in the English Channel immediately upon England's declaration of war with Germany. After the United States entered the war and troops landed in France, there was great need for direct communication with France that could not be intercepted by the enemy. As a military operation, the east end of the German cable was diverted into Cherbourg. Western Union built equipment for the Cherbourg end and trained an Army staff to operate it. At Christmas time 1944 a Western Union engineer was flown to Cherbourg to assist in getting traffic started.

Duplexing Finally Accomplished

One other chapter had been added to the cable history of the crossroads in 1928, when Western Union laid a second cable to Horta, this time from Bay Roberts, Newfoundland. Western Union engineers by that time had developed a modification in the method of loading a submarine cable so it might be duplexed. By "tapering" the loading — none at the extreme ends, light loading starting 160 nautical miles from shore and continuing for 69 miles, then full loading—it was thought possible to balance it. The cable was laid and tests confirmed the design data. Although this cable has never had sufficient message load to warrant working it at its highest speed, it has been worked experimentally at 75 cycles duplex—1800 letters per minute multiplex — in each direction simultaneously, thus breaking all cable speed records. Western Union's transatlantic "2-HO" via Horta is still the world's fastest submarine cable of comparable length.

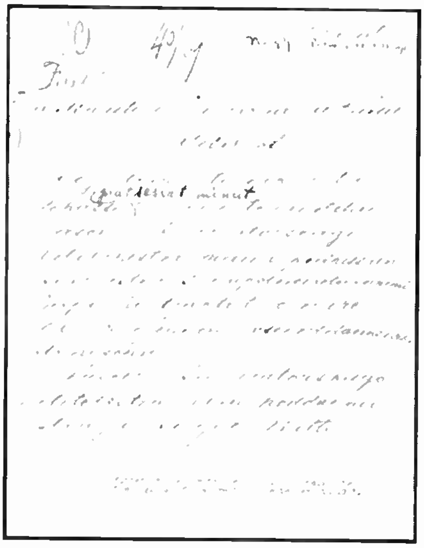
At Horta, as elsewhere, the tempo changed during European war years when the Azores became a landmark of shipping lanes and airways as well as cable routes. Today, relaxed again and quiet, this island village carries on with its vitally important role as a communications crossroads in the pulsing commercial life of many nations.

H. H. Haglund joined Western Union in 1911 working first as an installer and later as an automatic chief in charge of Barclay, Blue and Green Code Morkrum and Multiplex equipment. After graduation from the University of Utah he was transferred to the Automatic Engineer's department in New York. Assigned to Multiplex problems, he cooperated with the Bell Labs engineers in the design of special equipment for our first loaded transatlantic cable and supervised the installation and testing of this equipment at Horta. Subsequently Mr. Haglund has been in charge of various groups in the Plant and Engineering Department, and is at present Assistant Director of Applied Engineering. He is a member of the AIEE.

Telegraph History

The Treaty of Portsmouth, ending the Russo-Japanese War, was signed September 5, 1905, at Portsmouth, N. H. (U. S. A.) following mediation proposals by President Theodore Roosevelt. The Russians had suffered military disasters and were threatened with internal disorders when negotiations began on August 9.

Western Union handled most of the domestic press dispatches but Postal Telegraph Company had a lion's share of the cable business to Tokyo and St. Petersburg. Postal Manager Charles A. Richardson's interesting notebook, now preserved in the Western Union museum, includes the original cablegram to the Czar from Russian Envoy Serguei Witte telling that the treaty had been signed.



(Translation)

His Majesty the Emperor of Russia
Peterhof

Today on Tuesday at 3:50 (p.m.) by authorization of Your Imperial Majesty the peace treaty was signed by us jointly with the delegates of Japan.

Your Imperial Majesty's loyal subject (and servant)

Serguei Witte

In his notes about the peace conference, Mr. Richardson says,

"Mr. Witte, Russian Envoy, on account of his dislike for the sea voyage, left the *Mayflower* at Newport, going to Portsmouth by rail, arriving at midnight on Monday, August 7th.

"The Russian Government cablegrams averaged two hundred words," writes Mr. Richardson, "and were transmitted to the Cable stations in about five minutes. After transmission the cablegrams were taken to the Postal office and placed under lock and key, safe from the eyes of curious reporters, who were on the alert for material from which to fabricate predictions and gossip.

"Baron Komura and members of the Japanese Legation arrived on the *Mayflower* on Tuesday morning, August 8th. Operator H. H. Cooper immediately started for the Navy Yard in an automobile (hired by the Postal for emergencies). On arrival Cooper presented himself to Ass't Sec'y Pierce with a request that he be allowed to deliver in person to Baron Komura or his secretary important cablegrams. Cooper made his deliveries and arranged for a push-button call between the room used as an office by the Japanese and a response bell by which he would acknowledge each call, and ring the bell in the Japanese room when he had one to deliver.

"Cablegrams were sent to Tokyo and replies received in an hour. The service to London was, of course, much quicker. Newspaper cablegrams of 3000 words were transmitted to London and delivered to newspaper offices in thirty minutes. The foreigners were astounded and delighted at the celerity and accuracy of the service, which was in marked contrast to the service in European and Oriental countries. Some of the foreign correspondents could not write legible English and could not speak it, causing slow transmission and calling forth the most ingenious work to insure correct translation. In one case it required the combined intelligence of three transmitting operators to forward a press cablegram of 400 words and the operation consumed thirty minutes.

"At the signing of the treaty a flag was raised at the Navy Yard and instantly the secretary of the Japanese Embassy handed in 3000 words of code cablegrams for London and Tokyo.

"Many people of note visited the Postal office and watched with amazement the way the thousands of words of difficult code were disposed of. Among the visitors were Alexander Graham Bell and Charles J. Glidden of telephone fame. The envoys and correspondents left Newcastle together and in thirty minutes they were followed by the telegraph squads and the offices abandoned. The dismantling commenced at once. In two days not a trace remained of one of the most remarkable feats of the telegraph in history."

Wire and Cable in the Telegraph Industry

W. F. MARKLEY

PART II. OFFICE WIRE AND CABLE

STATION OR OFFICE WIRE

FOR MANY YEARS twisted pair and triple conductor wire employed for station or office wiring consisted of No. 20 A.w.g. tinned copper conductor insulated with rubber compound over which was woven a hard glazed cotton braid having a simple wax treatment to prevent fraying ("A" of Figure 7). Single conductor wire was also used for wiring equipment.

In order to improve the electrical efficiency of this wire, the rubber insulation was replaced with a tough extruded vinyl compound in a thickness of 15 mils, retaining the treated cotton outer braid ("B" of Figure 7). This design improved the performance of this wire considerably but the cotton braid lacked adequate serviceability. Subsequently, the cotton braid was replaced with an extruded electrical grade nylon in a nominal thickness of 3½ mils ("C" of Figure 7). The nominal over-all diameter of each single conductor now measures about 70 mils as compared with 107 mils for the original rubber insulated and braid covered wire. The nylon jacketed wire costs about the same as, and is easier to install than, the former standards. Indications are that this wire is giving outstanding performance in field service.

Figure 7. Triple conductor office wire, 20 A.w.g.
"A" Original standard-rubber insulated and cotton braid covering, o.d. 107 mils (each conductor).
"B" Intermediate standard-vinyl compound replaced rubber insulation.
"C" Present standard-nylon jacket substituted for cotton braid, o.d. 70 mils (each conductor).

A paper presented before the Winter General Meeting of the American Institute of Electrical Engineers in New York, N. Y., January 1953.

LOUD SPEAKER WIRE

Similarly, when it became necessary to design a 16 A.w.g. twisted pair wire for use in connecting groups of loud speakers to speaker selectors in public address systems in Western Union reperforator switching centers, vinyl compound and nylon jacket were standardized as the conductor covering. In this instance, however, by reason of the heavy wall of primary insulation, it was considered sufficient protection to extrude a single envelope of nylon over the two insulated conductors after pairing (Figure 8). Extruded nylon has the characteristic of conforming closely to the contour of the surface to which it is applied. This procedure provided adequate mechanical stability and effected economies in manufacture and installation as compared with a separate nylon jacket over each conductor.

SHIELDED TWISTED PAIR WIRE

Considerable time was devoted to the development of a No. 22 A.w.g. twisted pair wire, having an over-all woven metallic shield, required for certain circuits in electronic equipment. Initially, in the original design shown in "A" of Figure 9, there was some question as to how much of the surface of the twisted pair wire should be covered by the woven metallic braid.

For test purposes to determine this feature, lengths of twisted pair wire were made up having three nominal degrees of shielding, viz., 70, 85 and 100 percent coverage, respectively. The results of the electrical tests indicated that no significant difference in crosstalk, attributable to the various degrees of shield coverage, could be detected. The major contribution of the shield appeared to be the minimizing of direct capacitance between circuits. From a mechanical standpoint, that is, flexibility and minimum damage to the shield during severe bending and abuse in installation, the shield having the least coverage was the most desirable.

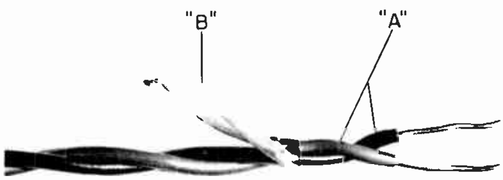


Figure 8. Loud speaker twisted pair wire, 16 A.w.g.
"A" Vinyl insulation.
"B" Envelope of extruded nylon.

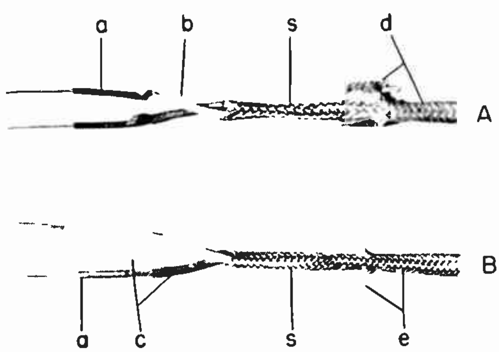


Figure 9. Shielded twisted pair wire, 22 A.w.g.
"A" old standard, "B" present standard.
a — vinyl insulation; b — lacquered cotton serving; c — nylon jacket; s — woven metallic shield; d — over-all lacquered cotton braid; e — over-all extruded nylon jacket.

While, at the low frequencies used on these pairs, it appeared that a coverage of 30 to 50 percent would be sufficient, it was decided, in view of the fact that commercial shields usually represented about 70 percent coverage, to standardize on the 70 percent value for this wire. A subsequent improvement in this wire is shown in "B" of Figure 9 which consists of replacing the lacquered cotton serving on the conductors and the treated cotton outer braid with extruded nylon.

SWITCHBOARD CORDS

Figure 10 illustrates the various stages in the development of switchboard cords. For many years these cords comprised copper tinsel conductors, each insulated with servings of cellulose acetate yarn, treated with a moistureproof compound over which was applied a soft cotton braid; these conductors, together with suitable fillers, were laid up to form a core which was covered with several cotton braids, the outer braid consisting of hard glazed cotton ("B" in Figure 10). These cords are subjected to considerable wear and abuse in service, as shown by the illustration at "A" in Figure 10, due to the continuous flexing and abrasion of pullies and weights.

In view of the fact that the hardest wear on these cords occurs in the outer braid, it was decided to substitute for the all-cotton cords a plastic cord, as shown at "C" in Figure 10, wherein extra flexible stranded conductors were employed, each insulated with a thin wall of extruded vinyl compound, laid up into a core with suitable fillers and covered with an over-all extruded vinyl jacket. These cords, however, proved unsatisfactory due to the difficulty of obtaining a thermoplastic jacket compound that possessed adequate flexibility without the undesirable characteristic of having the plasticizer ooze out from the compound during warm weather, a condition which made the cords sticky and extremely difficult to handle. Also, the excess plasticizer normally used in the jacket compound to provide flexibility resulted in a material that possessed inadequate abrasion and wear characteristics.

In order to overcome the undesirable features of the vinyl covered cords, the plastic jacket was replaced by a woven nylon braid ("D" in Figure 10), at which time a bronze tinsel conductor was adopted to provide superior strength and flexibility characteristics. The nylon jacket for these cords possesses excellent abrasion characteristics and resistance to oils, grease, and so forth, is extremely flexible, moisture resistant, and provides a long life. The thermoplastic insulation insures good electrical characteristics under ad-

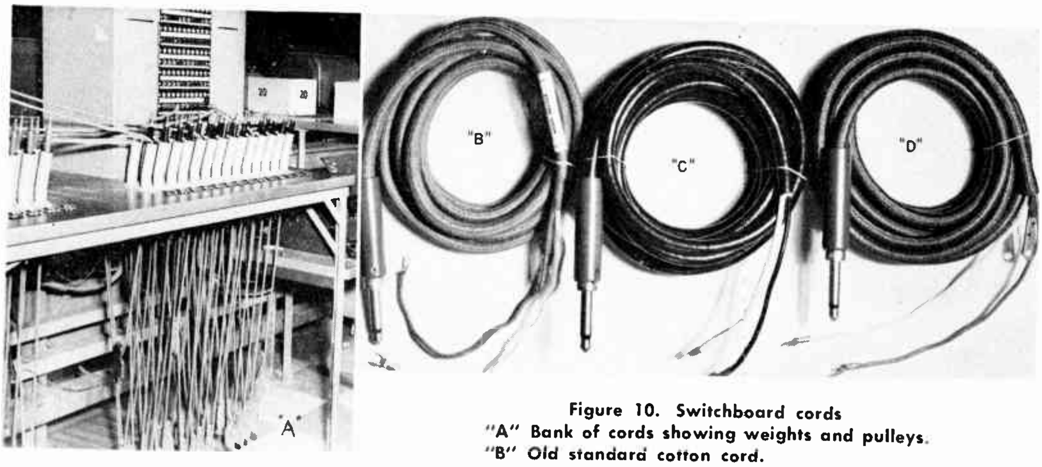


Figure 10. Switchboard cords
"A" Bank of cords showing weights and pulleys.
"B" Old standard cotton cord.
"C" Vinyl jacketed cord.
"D" Present woven nylon braid covered cord.

verse operating conditions, such as hot humid weather. Indications are that the service life of these cords will be several times that of the ordinary glazed cotton braided cords.

TICKER CABLE

Practically all of our cables required for inside use have been redesigned to provide for plastic primary insulation and jacketing compounds. In Figure 11 are shown the old, intermediate and present styles of 2- and 4-conductor ticker cables.

The old standard for these cables, as shown in "A" of Figure 11, comprised rubber-insulated and braid-covered conductors, rubber-filled core tape serving and a treated hard glazed over-all woven cotton braid. In the intermediate styles of these two cables, as shown at "B" of Figure 11, the insulation was changed to vinyl compound without a braid or jacket, and the core tape to a paper serving but retaining the outer braid cover. These changes not only materially improved the over-all serviceability of these cables but resulted in greatly reduced diameters.

At a later date, these cables were redesigned to provide an all-plastic cable wherein the vinyl insulation was protected with a nylon jacket, the core tape omitted, and an extruded vinyl sheath substituted for the cotton braid as illustrated at "C" of Figure 11. These final designs provide exceptional ease of installation and excellent performance in service, particularly in warm moist climates.

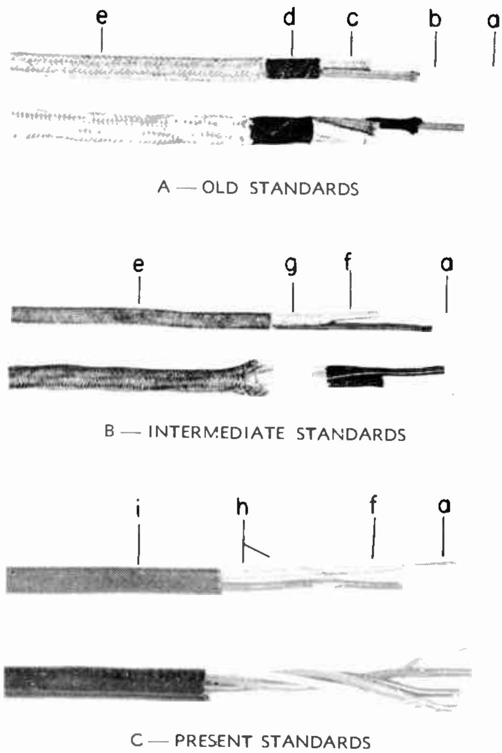


Figure 11. Ticker cables
2-conductor size 2 No. 20 A.w.g., parallel lay.
4-conductor size 4 No. 18 A.w.g., spiral-4.
a — tinned conductor; b — rubber insulation; c — cotton braid; d — rubber filled tape serving; e — over-all cotton braid; f — vinyl insulation; g — paper tape serving; h — nylon jacket; i — over-all vinyl jacket.

MULTIPLEX CABLE

Figure 12 illustrates another example of modernization of multiple conductor inside cables, supplied in several sizes, and shows the substitution of an all-plastic cable in lieu of rubber, silk and cotton combination for cable required in connection with the operation of multiplex equipment and impulse units. Here again, the primary insulation and jacket stock consist of vinyl compounds effecting a marked improvement in serviceability and a reduction in over-all diameter.

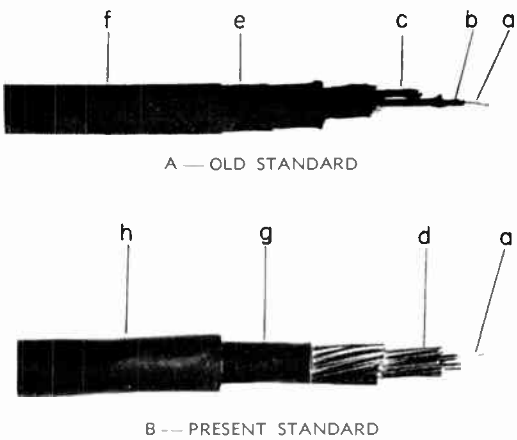


Figure 12. Cable for multiplex equipment and impulse units, 22 A.w.g.
a — tinned conductor; b — rubber insulation; c — silk braid; d — vinyl insulation; e — soft cotton inner braid; f — hard-glazed cotton outer braid; g — vinyl core tape; h — vinyl jacket.

OFFICE CABLE

Perhaps the most important development in inside cable is concerned with the redesign of enamel and textile insulated, multipair cable employed in large quantities for wiring offices. This cable is supplied in sizes varying from 3-pair to 50-pair. For a great many years the standard for this type of cable consisted of 22 A.w.g. solid copper conductors, each enamel insulated and covered with servings of silk and cotton yarn, which were laid up in pairs, with a concentric lay, into a core that was thoroughly saturated with a natural or mineral beeswax and paraffin mixture. Over this core were applied several spiral wrappings of heavy paper tape to serve primarily as a barrier for the flameproofing paint that was heavily applied to the over-all woven cotton braid which served as the jacket. This old design is shown in "A" of Figure 13.

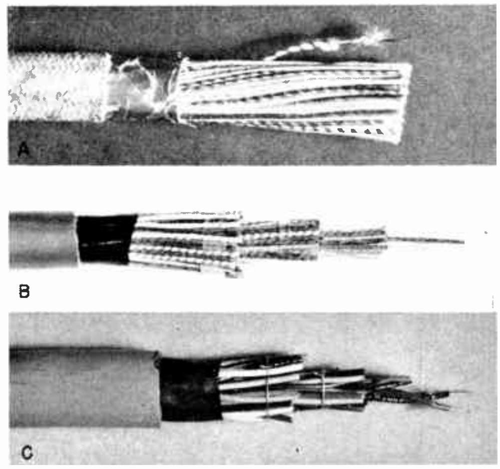


Figure 13. Office cables
"A" Old W.U. standard, enamel insulation and textile servings.
"B" Plastic design, polyethylene insulation and lacquered cotton serving.
"C" Present all-plastic standard, vinyl insulation and nylon.

This cable is subjected to considerable abrasion and abuse during installation in that it is pulled through conduit, run over steel bars and angles of supporting frames, given sharp bends, and tied in place on racks in groups. Also, much of this cable is employed in relatively short lengths involving numerous terminations. Frequently, long lengths of the jacket and paper tape must be removed to provide sufficient length for breaking-out the conductors at terminating points. The principal disadvantages in the use of this cable for many years have been the relatively high labor cost of terminating and the adverse effect of moisture on the operation of the circuits. Where this cable was used in areas having prolonged periods of hot humid weather, it was found necessary under such conditions to provide electric fans and heat to dry out the cables to effect adequate operation of the circuits. Also, it was observed that once this moisture had penetrated the cable it would take an extremely long time for the cable to dry out. In damp and wet locations, it was always necessary to supply this cable with a lead sheath. As we gathered knowledge with the performance and efficiency of plastic compounds, it became evident that a vast improvement could be made in the design of this office cable which would not only overcome the two major objections, referred to above, but which would also effect other advantages.

Polyethylene Cable

Accordingly, about five years ago, four plastic cables were made up in the 7-pair concentric lay size, each having a different type of extruded plastic insulation with a lacquered cotton overserve on the conductors; over the core was applied a 10-mil polyethylene tape and a cable jacket consisting of a lacquered woven cotton braid. For comparative test, a standard Western Union enamel and textile cable in 5-pair size was obtained. The covering for the tinned conductors in the four plastic cables comprised the following:

- Cable A — Nominal 7½ mils of vinyl compound and lacquered cotton serving.
- Cable B — Nominal 5 mils of vinyl compound and lacquered cotton serving.
- Cable C — Nominal 5 mils of polyethylene compound and lacquered cotton serving.
- Cable D — Nominal 3 mils of electrical grade nylon and lacquered cotton serving.

Figure 14 shows the appearance of these four plastic cables and the old Western Union standard enamel and textile insulated cable. Table 2 gives the detailed dimensional data for the cable conductors. In the "A," "B," "C," and "D" cables, the lacquered cotton serving was all about the same general character and thickness; in the standard enamel insulated cable this yarn covering comprised two rayon servings and a serving of marking cotton, all of which had a certain amount of mineral beeswax impregnation.

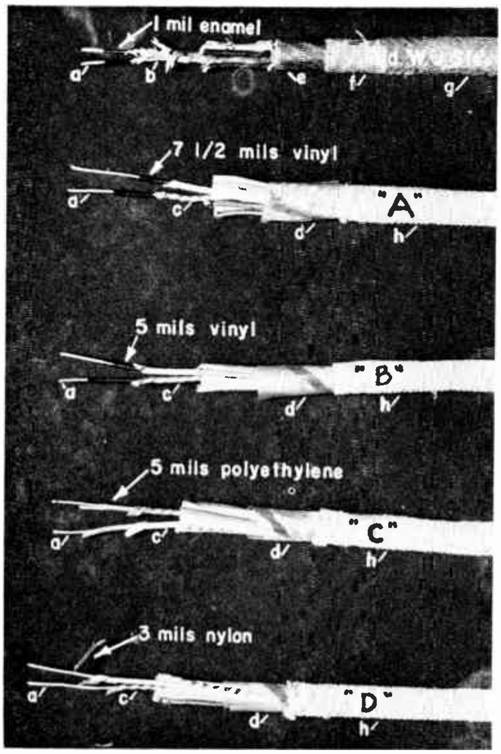


Figure 14. Experimental office cables
a — tinned conductor; b — rayon and cotton servings; c — lacquered cotton serving; d — polyethylene core tape; e — paper tape servings; f — cotton ribbon serving; g — heavy painted cotton braid; h — lacquered cotton braid.

Insulation resistance tests were conducted on 100-ft. lengths of these five cables after exposure for various periods of time to different atmospheric conditions varying from a temperature of 7.2 C. (45 F.) and 35 percent relative humidity to 35 C. (95 F.) and 90 percent relative humidity. These tests definitely indicated the outstanding superiority of the polyethylene, and the extremely poor insulating value of the nylon. On the basis of minimum insulation resistance values the 7½-mil vinyl insulated cable was superior to the standard enamel and textile insulated cable which was somewhat better than 5-mil vinyl insulated cable.

Similarly, capacitance tests were made on these lengths exposed to the same atmospheric conditions, as noted above, including immersion in water. In these tests the polyethylene insulation greatly excelled, as would be expected with this

TABLE II

Dimensional Data on Cable Conductors

IDENTIFICATION	DIAMETER OVER CONDUCTOR	DIAMETER OVER PLASTIC INSULATION	DIAMETER OVER YARN SERVING	RADIAL THICKNESS OF PLASTIC INSULATION	RADIAL THICKNESS OF YARN COVERING
	Mils	Mils	Mils	Mils	Mils
Cable "A" 7-1/2 mils vinyl-cotton	25	39	48	7.0	4.5
Cable "B" 5 mils vinyl-cotton	25	35	43	5.0	4.0
Cable "C" 5 mils polyethylene-cotton	25	36	44	5.5	4.0
Cable "D" 3 mils nylon-cotton	25	30	38	2.5	4.0
Old W.U. Std. enamel-cotton	25	27	50	1.0	11.5

low-loss compound. The nylon and the enamel were the least effective materials from a capacitance standpoint. The 7½- and 5-mil vinyl compounds gave capacitance values that were about on a par.

Voltage breakdown tests (a-c) were conducted on straight and helically wrapped sections of the finished conductors removed from the cables, both under dry conditions and after 24-hour immersion in water. Dry voltage tests were also made on lengths of the completed cables, both straight and after bending through 90 degrees over a ¼-in. radius and held for prolonged periods at different temperatures. Voltage breakdown tests were further conducted on straight lengths of the cables after being subjected to a uniformly distributed pressure of 10 lb. per running foot for 48 hours. In addition, coiled 10 ft. lengths of these cables were tested for voltage breakdown after being held for 24 hours at 35 C. (95 F.) and 56 percent relative humidity, as well as 35 C. (95 F.) and 94 percent relative humidity. All these tests were designed to simulate various conditions encountered in service. The voltage breakdown values were naturally highest for the 7½ mils of vinyl compound, by reason of the relatively heavy wall of insulation. The 5 mils of vinyl and polyethylene, respectively, gave about equal performance in these voltage tests. The nylon and enamel showed the lowest breakdown values.

The electrical performance of all the plastic compounds was surprisingly good when one considers the difficulty of satisfactorily extruding these thin walls together with the abuse and possible damage that occur in pairing and cabling.

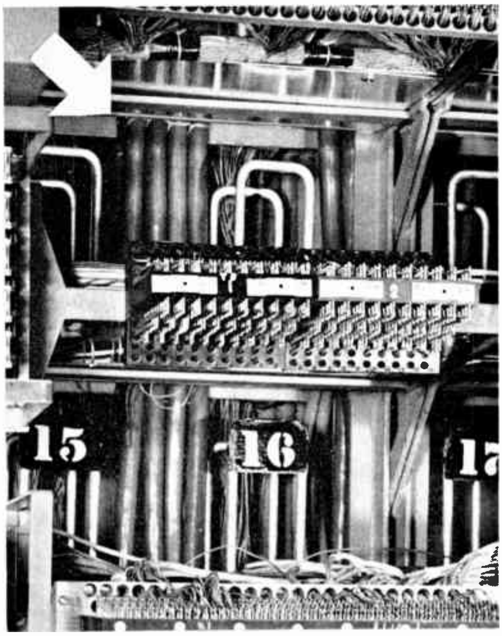


Figure 15. Section of transmitter-finder, showing installation of 40-pair polyethylene insulated office cables (arrow)

While both the 7½-mil vinyl and the 5-mil polyethylene insulated cables overcame the insulation weakness of the old standard enamel and textile insulated cable, the fact that the polyethylene gave such outstanding electrical performance led us to decide to give it a field trial. Accordingly, limited quantities in 40- and 50-pair size cables were made up with a nominal 5-mil wall of polyethylene insulation and lacquered cotton serving, with a vinyl tape placed longitudinally over the cable core and a vinyl jacket employed for the outer sheath as illustrated in "B" of Figure 13. These cables were installed in several of our reperforator offices as illustrated in Figure 15. The ease of installation and termination were favorably commented upon by our installers and the performance of these cables to date has been extremely satisfactory under all weather conditions.

Vinyl Cable

During the manufacture of these polyethylene insulated cables, it was observed that the thin wall of insulation was extremely fragile and easily damaged during processing and cabling. Inasmuch as the superior electrical characteristics of polyethylene were not required for this service and in view of the greater toughness of thin vinyl compounds, and furthermore since the 7½-mil vinyl insulated cable gave adequate electrical performance in the tests on the original experimental plastic cables referred to above, it was decided to substitute an 8- to 10-mil vinyl compound and a 3-mil nylon jacket for the polyethylene insulation and lacquered cotton serving, respectively. In other words, our standard 22-guage instrument wire, referred to above, was adopted for these cable conductors, an arrangement which simplified production schedules and factory inspection. This design, illustrated in "C" of Figure 13, represents our present standard. This same cable is now employed in damp and wet locations where formerly lead covered cable was required.

A further refinement in the design of the plastic cable consisted of providing a lay-up for the pairs that permitted the conductors to break-out easily from their natural position in the cable during the terminating operation, thus reducing to a minimum the bending and twisting of the conductors at the soldered butts. This feature not only facilitates the terminating work but also provides a much neater appearance of the cable at the termination. Figure 16 shows at "A" the positioning of the conductors in the old 40-pair enamel insulated cable, wherein the pairs follow in numerical sequence around the cable in the order of termination. At "B" of Figure 16, for the same size plastic cable, the pairs follow in numerical sequence back and forth across the cable. From the heavy irregular outlines in the diagrams it can be observed, when mounting the cable butt on a standard Western Union 80-wire, 8-conductor level terminal block, that severe distortion of the conductors takes place as successive groups of four pairs break-out in the enamel cable, whereas with the plastic cable these groups fan out in their normal position.

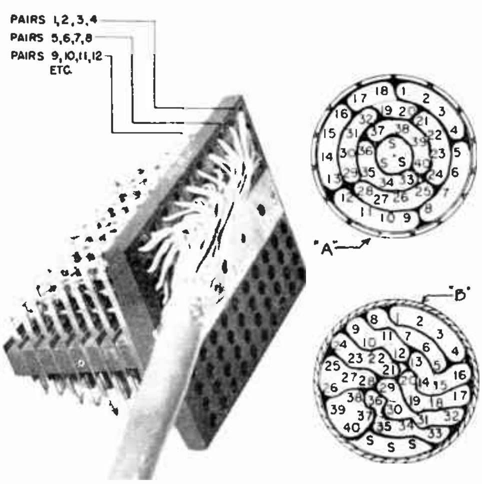


Figure 16, Termination of butt of 40-pair (plus 3 spare pairs) polyethylene insulated office cable on standard W.U. terminal block, indicating the position of successive groups of 4 pairs at each 8-conductor level.
"A" shows the old standard method of positioning the pairs.
"B" indicates the new method adopted for the all-plastic cable.

In standardizing the use of plastic office cable for installation, not only in dry locations in offices and buildings, but also in damp or wet cellars and floor and wall ducts where rats and mice are known to exist, the question was raised as to whether this new cable would be attacked by such rodents. Indications are that the plastic compounds are practically as resistant to this type of failure as lead sheath, which, on occasion, has been chewed by badly starved rats, squirrels, and so forth.

Relative Costs

The cost of the all-plastic cable in the smaller sizes is somewhat greater than that of the old enamel-insulated cable but in the larger sizes it is appreciably cheaper. Also, the time consumed in terminating the plastic-insulated cable is only 50 to 60 percent of that required for the enamel type, resulting in a substantial labor saving, inasmuch as a large percentage of this cable is installed in short lengths varying from 8 to 30 feet, thereby calling for the termination of from 6 to 24 butts per 100 feet of cable. This is due to the extreme ease of stripping the insulation on the plastic cable thus exposing the tinned conductors as compared with scraping the enamel coating on the conductors in the textile cable, a condition which automatically removes the tin coating as well. In addition, with the plastic cable, all of the stripping on a number of lengths can be done at one time, and all of the soldering work carried out at a later time regardless of the interval between stripping and soldering. In the enamel type of cable, it is necessary to solder almost immediately after stripping because the copper conductors, bared during the stripping operation, readily tarnish and oxidize.

Advantages of All-Plastic Cable

The principal advantages in the use of the all-plastic cable over the former standard having enamel insulated conductors can be summarized as follows:

1. Improved moisture resistance.
2. Superior electrical and physical properties and flexibility.
3. Increased resistance to fungus.
4. Better flame resistance.
5. Sharper coding colors for the insulated conductors.
6. Greater ease of installation and terminating effecting vastly reduced installation costs.

Part III of this article will describe Outside Wire and Cable.

Mr. Markley's biography appeared in TECHNICAL REVIEW for April 1953.

Patents Recently Issued to Western Union

Telegraph Repeater Switching System

P. R. Easterlin

2,630,483—March 3, 1953

An inverse repeater network in which printer stations in outoffices in different locations connect themselves into or out of communication with any one or more of the other printer stations in the network without interfering with other connections. The system facilitates testing and regulating communication between attendants in distantly located offices on a nationwide basis for prompt maintenance and restoration of telegraph channels, and provides an integrated and versatile dispatcher test wire system.

Phasing and Synchronizing Device for Facsimile Machines

R. J. Wise

2,630,495—March 3, 1953

A synchronous motor, upon receipt of a phasing signal, takes over the driving of the receiver scanning shaft, while the shaft is rotating under the control of a nonsynchronous motor. The nonsynchronous motor drives the shaft, which bears one part of a clutch, at above or below synchronous speed; the second part of the clutch is idly driven by a synchronous motor at synchronous speed. The receipt of a phasing signal energizes a magnet to couple the two parts of the clutch, while rotating, to drive the shaft by the synchronous motor.

Telegraph Exchange System

W. B. Blanton, F. L. Currie, G. W. Janson

2,632,043—March 17, 1953

An operator directs a message, from any one of several transmitters, through the switching equipment bv pressing two push buttons in sequence. Pressing the initiate button, associated with an individual transmitter, seizes the connector circuit exclusively; pressing any one of the destination buttons, thereafter, causes connection of that transmitter to the desired sending circuit and starts transmission. The connector circuit is thereupon released for further initiations; the selected circuit is also released at the end of the first message.

Telegraph Reperforator Switching System

G. G. Light

2,632,044—March 17, 1953

At the central office each heavily loaded receiving circuit terminates in an "alternator" which directs received messages alternately to two printer-perforators. Operation of a push button connects a tape transmitter associated with each perforator to a sending circuit, automatically initiating transmission. A numbering machine transmits a message number ahead of each message. Rotary switches operate to connect monitor printers, which copy the first line of each message including the message number, to provide a printed record of each switching operation. Concentrators function to connect the lowest-numbered idle monitor printer available.

Means for Increasing the Telegraph Signalling Speed of Submarine Telegraph Cables

H. F. Wilder

2,637,784—May 5, 1953

A repeater for installation in a nonloaded submarine cable at the edge of the continental shelf for the purpose of amplifying incoming signals for sending through the high noise level encountered in the shallow shelf area. Substantial increase in signalling speed is attained. Dependent claims cover also battery regulation, earth current compensation, signal shaping, and remote control of a switch for introducing a spare repeater and performing other functions.

Facsimile Keying Circuit

F. T. Turner

2,639,321—May 19, 1953

The stylus circuit resistance variations produced by scanning are used to key directly the source of carrier signals. A multivibrator circuit is prevented from oscillating when unmarked areas are scanned and oscillates when marked areas are scanned.

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