The first major innovation in Bell System drop wire since 1946, when a neoprene jacket was introduced, new all-vinyl insulation offers such advantages as lower attenuation, greater abrasion resistance, improved shear and compression strength, and lower cost.

All-Vinyl Insulation for Aerial Drop Wire

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AERIAL DROP WIRE is a component of loop plant which extends the telephone circuit from the distribution cable to the point of entrance into the customer's dwelling. It has been the object of research and development since the Bell System's infancy and, surprisingly, it still is.

It has evolved from an unbalanced bare iron wire line, a copy of the best telegraph line then available (circa 1890), to its present form, which was standardized in 1946. The key developments in this period were the transition from an unbalanced single wire to a balanced pair of wires, and the introduction of rubber insulation, weather-resistant textile jacketing, and smaller and stronger conductors. These efforts to improve the transmission quality of the wire were concurrent with efforts to reduce its cost.

In spite of substantial improvements in the quality of the rubber insulation and textile braid jacket, the median life of the wire was only 12 years—a limitation imposed principally by weather resistance of the textile jacket, or braid. Not until the large-scale commercial availability of chloroprene rubber (neoprene) in 1946 was the life substantially improved—to about 20 years.

Neoprene, developed by DuPont in the 1930s, was first evaluated for drop-wire jackets in 1940. However, many improvements in neoprene formulation were required before it could be adopted for drop wire. One such improvement was the inclusion of a proper wax blend which, by exuding to the surface, formed a coating that protected against ozone attack when the wire was bent or stressed and also lubricated the surface to improve resistance to scuffing and abrasion. During the early use of neoprene-insulated, or "C-drop," wire, it was discovered that the neoprene jacket showed a sizable initial loss in elongation (the amount the insulation can be stretched before breaking) after outdoor weathering. Further study, however, revealed that the rate of loss decreased rapidly after the initial change and the elongation stabilized at a relatively satisfactory working level.

Improvements in C-drop wire were complemented by the benefits of the continuous vulcanization process developed by Western Electric. This resulted in high production rates for the wire at reduced unit costs. Neoprene not only improved weathering life—it also reduced moisture absorption and increased dielectric strength and abrasion resistance. No longer would frayed textile dangle from the lines like some ancient cryptic semaphore. However, textile did not disappear; instead it was moved beneath the jacket and "served" (spirally wrapped) around the rubber insulation.

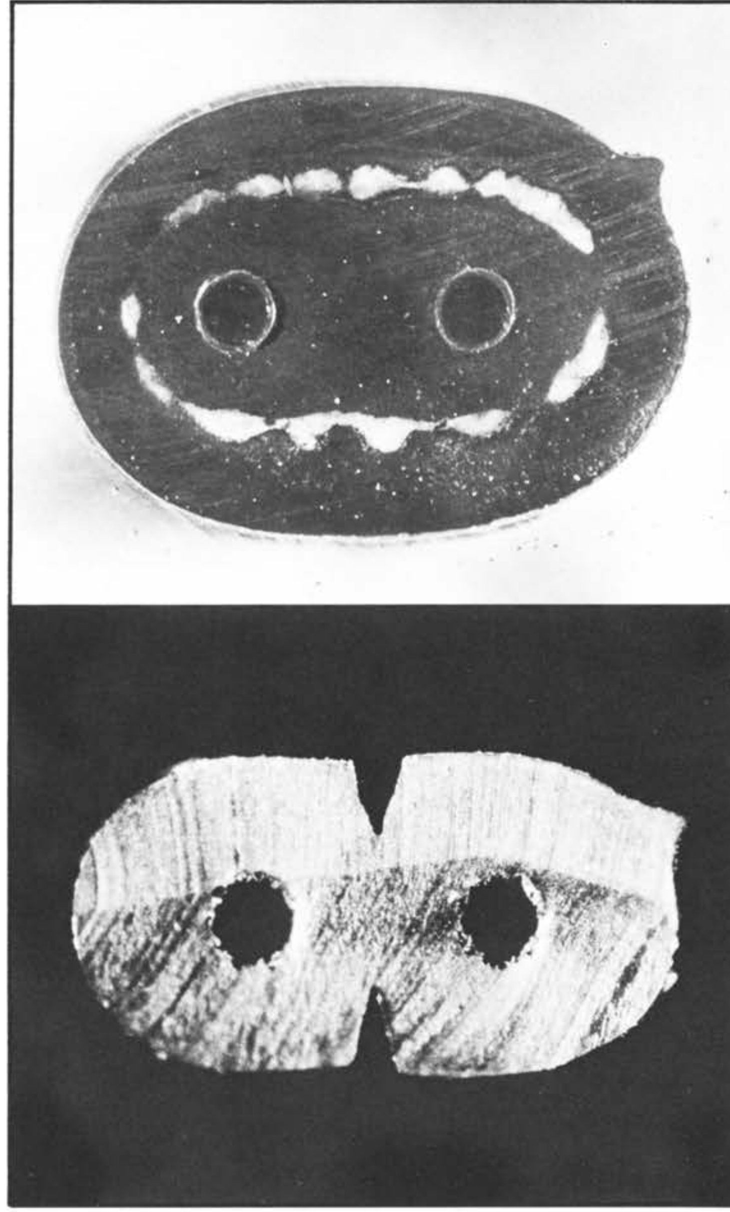
New drop wire insulated with polyvinyl chloride (PVC) makes the installation job easier. Here, at left, it is being used in a test installation by John Apgar of Bell Labs' Chester, New Jersey, location. The wire is 30 percent lighter than the wire it replaces and does not kink. The new wire's 10 percent lower cost means large savings for the Operating Companies. PVC-insulated drop wire can be stripped with a pair of ordinary diagonal pliers, shown at right. The old wire requires a special stripping tool.

There, protected from the elements, it acted as a constant reinforcement, limiting cold flow of the insulation caused by the compressive forces applied at the support clamps.

A completely new materials concept for Bell System aerial drop wire did not appear until 1957 when Bell Laboratories first explored the use of an all-vinyl plastic (polyvinyl chloride, or PVC) insulation. One incentive was reduced manufacturing costs through elimination of the jacket and the textile reinforcement (the serving process is a relatively slow one). Equally important were the expected benefits of smaller size, lighter weight, improved abrasion resistance and—for installers—the elimination of a separate jacket-stripping tool. The main deficiency of the early PVC design was the lack of an efficient, low-cost method of controlling conductor-insulation adhesion. A certain level of adhesion is required to prevent shearing of the insulation beneath the support clamps caused by heavy wind or ice loads.

A solution to the PVC-copper adhesion problem did not come until 1966, when it was found that, in the laboratory at least, the desired bond could be obtained by fusing a vinyl plastic to a copper surface preheated to a temperature between 200 and 250°C. It was also observed that the reliability of making strong bonds could be increased by incorporating an epoxy resin in the vinyl plastic. Bonds obtained in this fashion, when prepared under suitable conditions, have a strength exceeding that of the cohesion of the plastic. The reaction that occurs at the plastic-copper interface has not been determined with certainty, but it is believed that through dehydrochlorination a partially oxidized polyene is formed. This substance, because of its active polar sites for chemical bonds, would be expected to show high adhesion.

With this information the problem became a matter of applying the laboratory technique to drop wire manufacture—a task accomplished by Western Electric engineers. In manufacture of



The difference between old and new drop wire is evident in these cross sections (actual width of each cross section is about 5/16 inch). The old "C-drop" wire (top) has a layered construction, composed of rubber insulation, textile reinforcement, and neoprene jacket. The insulation of the new "F-drop" wire (bottom), however, is made of a single material—a specially formulated polyvinyl chloride (PVC) *plastic possessing superior properties.*

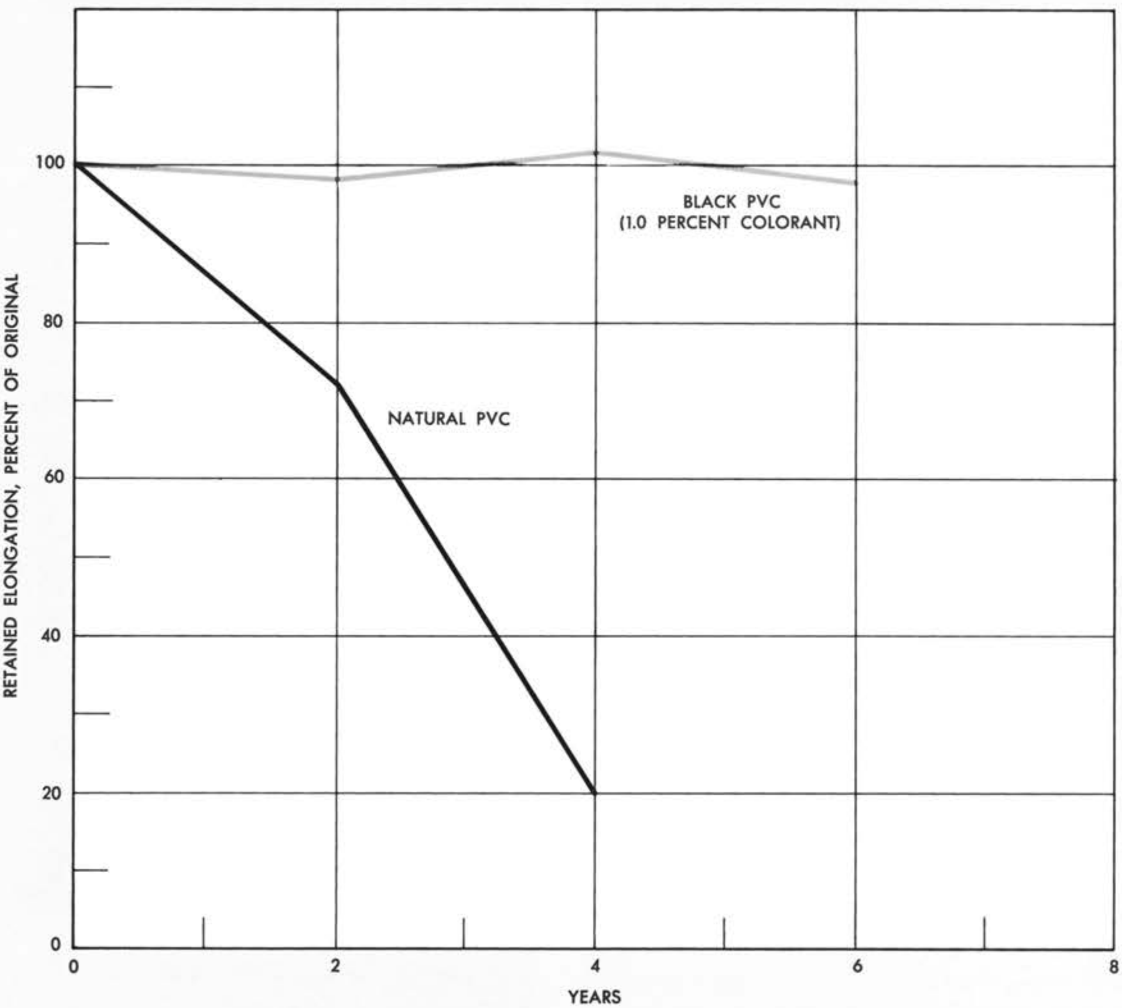
the new drop wire, the bare conductors (of copper-plated steel) are preheated to the desired temperatures just before they enter the extruder, where they receive a coating of the plastic. With this process, bonds requiring a force of 33 pounds to strip a 3/8-inch length of conductor have been attained. This is more than adequate, since the value for the rubber insulation on C-drop wire is approximately 15 pounds, which has sufficed in service. Outdoor aging tests for up to three years on the plastic-to-copper bonds indicate that they are not affected by seasonal changes and may be expected to retain their strength in service. The new method of manufacturing plastic drop wire also has an economic advantage over other processes in that it eliminates an adhesive priming step that is usually employed to obtain an adequate plastic-to-metal bond.

To meet the general design requirements for a PVC, or "F-drop," wire it was necessary to formulate a vinyl plastic specifically for this purpose. Since the wire is intended for outdoor service, flexibility at low temperature is essential. This requirement was met by striking a satisfactory balance between the PVC resin and a plasticizer having low-temperature flexibility. The balance was at first incompatible with the high insulation resistance required, but through adjustment—principally in stabilizer and filler content—the difficulty was overcome and a tenfold increase in insulation resistance above that of the initial vinyl plastic formulation was realized.

It is also necessary to protect PVC for outdoor use from degradation by sunlight. Carbon-black pigmentation in the proper concentration is therefore included in the formulation. Carbon black, dispersed throughout the PVC, acts as a light screen (see illustration, page 184).

No protection against ozone attack is necessary, since PVC is inherently resistant to this constituent of the atmosphere. However, since drop wire is used close to power lines and comes in contact with customer's premises, it must resist flame propagation. PVC has a natural advantage in this respect because of its chlorine content, which tends to suppress burning. In the drop wire plastic, to further reduce any hazard, this advantage has been supplemented by the addition of two flame retardants.

Tests of experimental wire structures proved that a satisfactory PVC insulation had been achieved. The electrical and mechanical properties of the wire can best be judged in relation to the older C-drop wire. The key electrical properties of drop wire are the dc insulation resistance and ac attenuation. The dc insulation resistance of the PVC drop wire is somewhat less than that of C-drop wire, but still is above the required value by two orders of magnitude. The transmission loss (ac attenuation) of the PVC drop wire is over 20 percent less than that of C-drop wire, primarily because of the lower effective dielectric constant of PVC (see illustration, page 185). Attenuation is measured over a range that extends above the usual voice frequency range. This is done in order to establish loss at the frequencies that would be



Carbon-black pigmentation is included in the PVC *formulation. The carbon black does not allow sunlight to penetrate, thereby preventing the insulation from degrading. The natural* PVC *hardens so that after four years' exposure it would break after being stretched to only 20 percent of its original value. Data shown here are for sheet plastics exposed to the sun in the southern United States.*

used if a subscriber carrier system is employed to derive a second circuit.

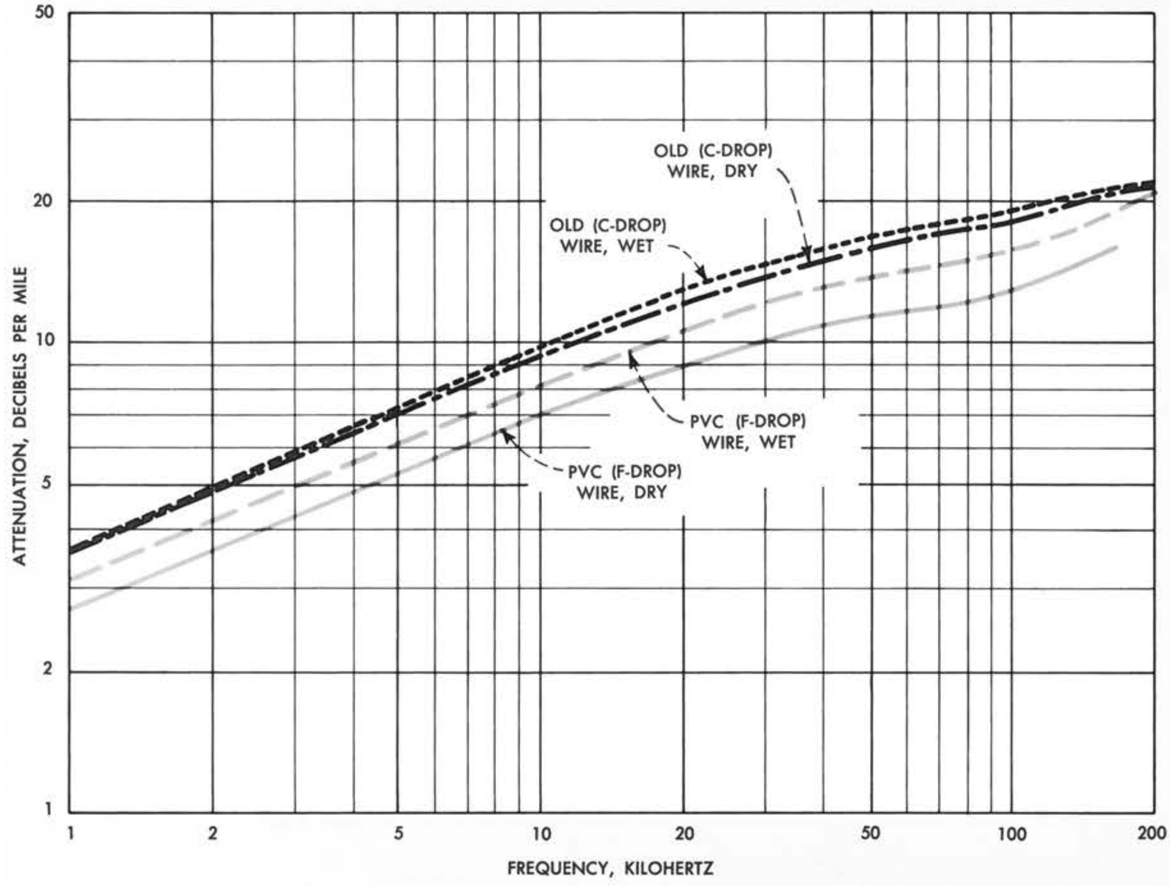
As shown in the figure, the attenuation changes when the wire is wet. Because drop wire does not contain a shield, attenuation is increased by rain, which itself acts as an electrostatic shield at the outer surface of the insulation.

As previously mentioned, lighter weight, smaller size, and improved abrasion resistance were the expected benefits of the PVC-insulated drop wire. A 30 percent reduction in weight (31.0 pounds per 1000 feet vs. 43.5 pounds per 1000 feet) and a 35 percent reduction in cross-sectional area (0.035 square inch vs. 0.054 square inch) were realized. Abrasion resistance was likewise increased—by a factor of 14 on the average (see bottom illustration, opposite page).

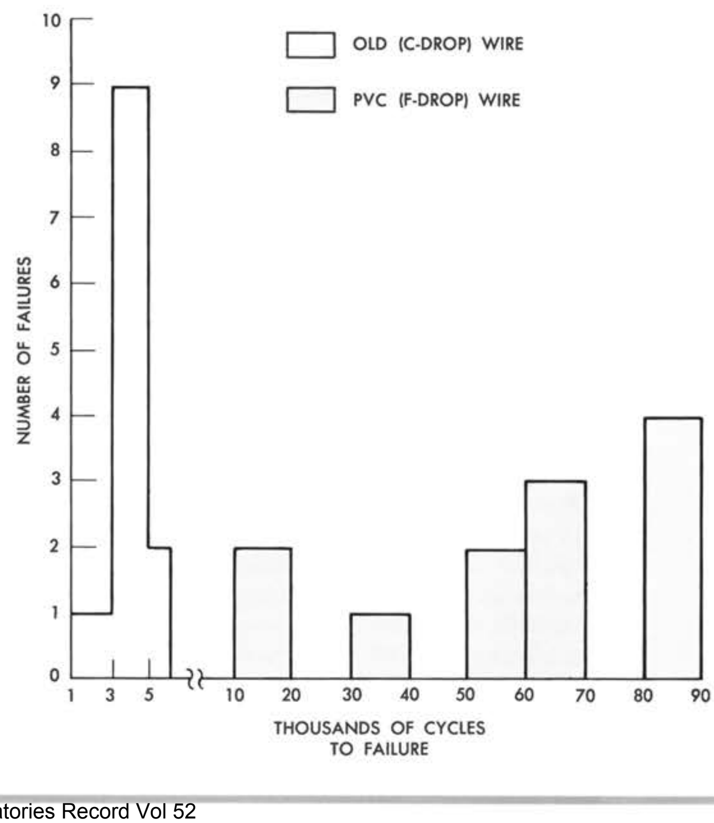
Smaller size and lighter weight in no way compromise the resistance of PVC drop wire to the compression and shearing forces applied to it at support clamps—forces derived from wind and ice loads and from the tension required to place the wire in a span. Over a wide range of deadweight load and temperature the plastic drop wire is superior to its predecessor in compression and shear strength (see illustration, page 186).

Equally important were low-temperature impact resistance and flexibility. Both C-drop wire and the PVC structure can be wrapped about themselves at −40°F without developing cracks; they are capable of absorbing impact energy of 40 inch-pounds along a 2-inch length of wire at −20°F without developing cracks. Such performance is necessary to withstand the rigors of normal handling, installation, and service life.

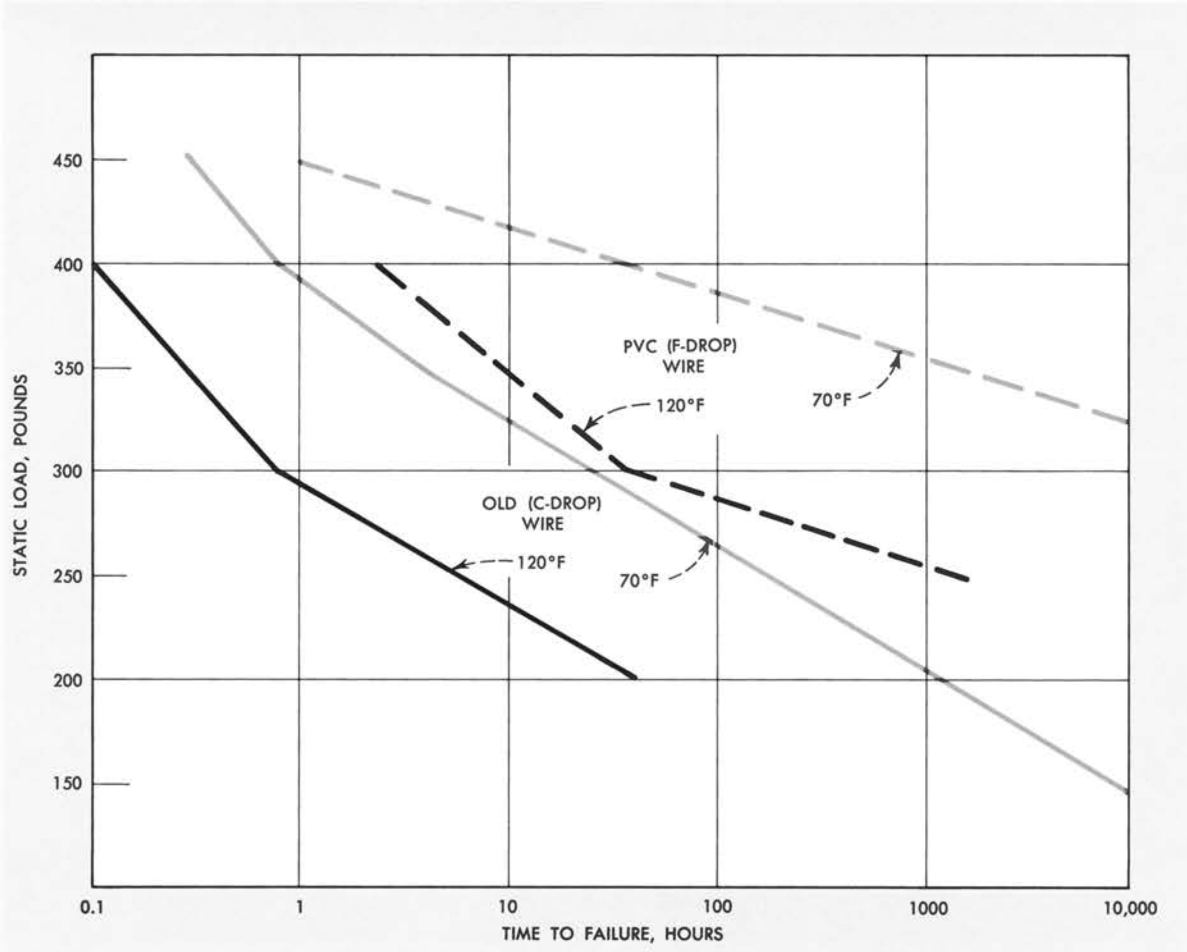
A Western Electric pilot line manufacturing



Moisture on the surface of drop wire acts as an electrostatic shield, increasing the attenuation of the wire with frequency. With the new PVC-*insulated drop wire, however, attenuation is less.*



The new PVC-*insulated drop wire has much better abrasion resistance than its predecessor; therefore fewer replacements for wear should be necessary. In abrasion tests, all samples of the old "C-drop" wire failed well below 10,000 abrasion cycles. All the* PVC *wire samples lasted for 10,000 cycles and some for as many as 80-90,000 cycles.*



PVC-insulated drop wire has superior compression and shear strength, as represented by the data plotted here for static load tests. Standard wedge-type clamps were used to support the aerial wire.

facility was sufficiently advanced by 1970 to produce relatively large quantities of the PVC wire for field-trial purposes. Through cooperation with South Central Bell, New England Telephone, and Michigan Bell, trial sites were selected in Gulfport, Mississippi, Augusta/Brunswick, Maine, and Traverse City, Michigan. Gulfport was chosen because of its high incidence of lightning, high relative humidity and temperature, and extremely corrosive coastal environment. Maine and Michigan were chosen because of their extended periods of below-freezing temperatures.

Each area received 100,000 feet (about 20 miles) of wire, enough for approximately 500 installations. The Operating Companies were requested to install it according to the practices for C-drop wire, and to keep detailed records on the service performance of 100 installations over a two-year period.

It was learned from the installers that the handling, placing, and terminating characteristics were similar to those of C-drop wire. The PVC drop wire could be readily terminated with only diagonal pliers, a standard item in the installer's tool pouch. The braid slitter—formerly a necessary wire termination tool—could be eliminated (see illustration, page 182). The trial further confirmed that practically all C-drop wire hardware (clips, clamps, and attachment devices) could be used interchangeably with the PVC drop wire. During the installations below 0°F it was learned that a slightly deeper V-shaped notch and slightly softer insulation would eliminate exposing the conductor when insulated conductors were separated for termination.

Other benefits of the PVC drop wire which assume importance in our ecology-conscious society are a cleaner manufacturing process due to reduced amounts of carbon black and the possibility of recycling used PVC insulation. An estimated 10 percent reduction in price over C-drop wire is likewise a benefit to the Operating Companies.

These benefits—coupled with the satisfactory user experience—have led to the adoption of PVC drop wire as a standardized product, now designated F-drop wire AT-8668. It is now being manufactured at the Western Electric Baltimore Works. □