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WT4 Millimeter Waveguide System:

Introduction

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In this special WT4 issue of the B.S.T.J., we describe the design of a long-haul millimeter waveguide transmission system capable of carrying up to 475,000 two-way voice circuits, and give the results of measurements on a 14-km test system. The WT4/WT4A system transmits high-speed digital bit streams in the DS-4 format (274 Mbits/sec), which can carry any form of voice, data, or video communications. The bit error rate is designed to be 10^{-7} or better on a coast-to-coast circuit. The waveguide medium is designed to be installed on readily obtainable right-of-way, utilizing standard construction techniques for most operations. The installed medium features low signal loss, allowing extremely wide repeater spacings, and rugged construction, providing significantly higher reliability than any existing medium. Maintenance and restoration procedures and equipment have been developed and demonstrated for both repeaters and medium. For a fully loaded system, the cost per circuit mile will be significantly below that of any existing long-haul system.

This development is the direct result of over four decades of Bell System research and development activities on waveguides, which began with the experimental identification of waveguide modes by G. C. Southworth in 1931 and 1932, and the theoretical discovery of the low-loss property of the TE_{01} mode by J. R. Carson, S. P. Mead, and S. A. Schelkunoff in 1933.

After the early discoveries, interest and effort in waveguides and high frequencies grew steadily at Bell Laboratories, forming the basis for the development of radar during World War II, and of microwave radio relay and satellite communications after the war. In the 1950s and early 1960s, many fundamental contributions to the understanding and realization of waveguide transmission via the TE_{01} mode and to millimeter-wave repeater concepts and components were made at the Holmdel and Crawford Hill laboratories by H. T. Friis, S. E. Miller, and their coworkers. An exploratory development effort was begun in 1959 on a system utilizing 2-inch waveguide and traveling-wave-tube repeaters, but was abandoned in 1962 because of TWT cost and reliability problems and because the capacity exceeded then-current Bell System needs.

In 1968, after six years of continuous long-haul growth and with high-frequency solid-state devices such as IMPATTs a reality, exploratory development of an all solid-state system was undertaken as a joint project of Bell Laboratories, Western Electric Company, and the Long Lines Department of AT&T. This effort has led to the results described in this issue.

As Southworth himself wrote in 1962, referring to the early years when millimeter waves were only a dream,

> "Almost from the first, however, the possibility of obtaining low attenuations from the use of circular-electric waves, carrying with it, at the same time, the possibility of extremely high frequencies and accordingly vastly wider bands of frequencies appeared as a fabulous El Dorado always beckoning us onward."

The path has, of course, not been an easy one nor have we yet reached its end. Although the technical problems have been solved, the economic ones have proven more formidable. Being a high-technology right-of-way system, waveguide is inherently expensive. But because of its loss characteristic, it is also inherently a high-capacity system, so that its cost per circuit is still attractively low. However, for its low costs to be realized, it must be used on routes of sufficiently large circuit cross-section and growth rate that it fills in a reasonable length of time. In recent years, after several decades of consistently rapid growth and continuing need for ever-larger systems, the growth rate of the Bell System long-haul network has declined. Thus the immediate need for a system of such large capacity as WT4 has decreased and, as of this writing, the date of first commercial deployment of waveguide is uncertain.

Since the responsibility for system design, specification and testing resided with Bell Telephone Laboratories, the authors of the papers in this issue are primarily Bell Labs people. However, that fact in no way reflects the relative contributions of the other partners in the project. The close interaction with Western and Long Lines at every stage of the development has had a profound effect on the tradeoffs in the design, manufacture, installation and operation of the system, and has resulted in many of the most attractive system features.

M. P. Eleftherion and his coworkers at Western Electric's Engineering Research Center were responsible for the development of the waveguide manufacturing processes and the incorporation of these processes into a pilot plant which fabricated the waveguide for the 14-kilometer field test. The wide repeater spacings realized were in a large part due to the Western Electric work on controlling steel tube geometry and on processes which led to low waveguide ohmic dissipation. The Western Electric manufacturing engineers at Merrimack Valley, in particular D. P. Farley and J. W. Thomas, provided the guidance to bring the electronics from the "brassboard" stage to the state of being a manufacturable product.

D. E. Derringer of Long Lines Headquarters and his co-workers in Engineering and Operations continually stressed the realities of right-of-way construction and the importance of reliability and maintenance of both the medium and the electronics. They encouraged the development of and made many contributions to the two-stage waveguide installation technique described in this issue.

The Northeastern Area of Long Lines had the responsibility for right-of-way procurement, engineering, and installation of the 14-km field test. Much of the success of the field test must be credited to the excellent work performed by these groups.