Fiber-to-the-Home

By Peter Kaiser and Paul W. Shumate

Bringing "Fiber-to-the-Home" has recently captivated the imagination and business instinct of the telecommunications industry and equipment manufacturers. With the prospect of fiber being widely deployed in the "last mile" of the telephone network, and with customers having access to nearly unlimited bandwidth, some see an opportunity for a large variety of novel broadband services with ensuing new revenue possibilities. Others see an opportunity for the mass-fabrication of optical communication equipment and new consumer electronics. In fact, by providing end-to-end fiber connectivity, Fiber-to-the-Home (FFTH, including business and commercial customers), is providing nothing less than the physical infrastructure for the broadband telecommunications network of the much-heralded "Information Age" of tomorrow.

Some of the broadband services envisioned are high-speed data transmission for high-resolution graphics and image; conventional and advanced television, including HDTV; video conferencing, video-on-demand; and other interactive video services, among others. Eventually such services are expected to be carried by a single-mode-fiber-based broadband integrated services digital network (BISDN) [1–4] whose standardization is well advanced in both the national and international standards bodies, as discussed below.

Interim methods and technologies to introduce fiber in the subscriber loop have been categorized as "Fiber-to-the-Home" trial concepts, with "Home" being substituted by "Customer" as noted above, or "Curb" and "Pedestal"—depending on the location of the fiber termination in a particular application. This paper analyzes some of the aspects of FTTH and relates them to the evolving BISDN network.

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Historical background

The emergence of the FTTH concept followed the highly successful application of fiber in the long-distance, inter-office, and loop-feeder networks of the Operating Telephone Companies (OTCs). The cost-effectiveness of ever higher-speed fiber transmission—which has reached the 1.7 Gigabit/sec rate in commercial trunk systems today, with up to 10 Gb/s systems being contemplated for commercial use in the future—increasingly justified the use of fiber over metallic cable, with the result that now more than 4 million fiber kilometers have been installed in the public telecommunications network in the United States alone.

FTTH also followed a series of broadband experiments performed in the past decade in various countries, all of which demonstrated the viability of fiber technology for such applications, but fell short of meeting the cost objectives and of identifying a viable set of revenue-producing new broadband services. The FTTH concept evolved with the intent of achieving an early and low-cost introduction of optical fiber in the subscriber-loop. Services offered initially concentrate on conventional voice and data, and to a limited degree on video transmission, with the latter being offered in cooperation with CATV companies.

Some advantages of pursuing the FTTH concept are: experience is gained with installing, testing, and maintaining fiber technology in the cost-sensitive loop environment; the potential of providing fiber-based services can be studied and customer response can be evaluated; powering, operations, maintenance, security, and privacy issues are being addressed; and service-specific billing issues are receiving early attention. Furthermore, possible alliances between OTCs and CATV companies are being explored and regulatory issues are being worked on, so that other service industries (such as the movie and broadcasting industries, as well as the education, publishing, and law-enforcement sectors, for example) can more readily recognize the present status, the future potential, and the cost effectiveness of this new technology. Provided that single-mode fiber with its immense bandwidth is used from the beginning, FTTH will also provide the physical infrastructure to facilitate the introduction of future BISDN technologies.

The challenges FTTH poses to optical communication technologists include the need for new device functionality for use in non-traditional architectures in order to reduce costs, and the need for cost-effective, high-reliability opto-electronic integrated circuits, among others. As a result, "Fiber-to-the-Home" was chosen as the dominant theme at the 12th Conference on Optical Fiber Communication, held in January of this year in Houston.

At that meeting, Richard Snelling from Southern Bell cited a study several years ago that helped to stimulate the FTTH movement. The study concluded that sometime in the early 1990s it will become less costly to provide even plain old telephone service (POTS) on optical fiber rather than on metallic cable.[5] This was projected on the basis of a continuing decline of fiber systems costs on one hand, and the ever increasing metallic systems costs, on the other. As a result, it will soon no longer be necessary to wait for the emergence of marketable broadband services to justify the introduction of fiber in the subscriber loop. Rather, one will begin with fiber deployment in the subscriber loop—with higher-speed and broadband services added at the incremental cost of the terminal equipment as the demand for such services arises later.

Following the conclusions of their studies—which were later confirmed by others—the first FTTH concept trials in the United States were undertaken by Southern Bell at Hunter's Creek and in the Heathrow community near Orlando. In the meantime, a total of 21 FTTH projects have been announced (Table 1), with about half of them presently being installed.

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Fiber-to-the-Home costs

As is generally acknowledged, the most important obstacle in the way of early fiber deployment in the subscriber loop is costs. To clarify the cost question, a study was recently undertaken by Bellcore that took into account relevant FTTH technologies such as electronics, opto-electronics, fiber cable, splices and connectors, as well as current volume, learning-curve rates, and labor.[6]

Assuming further a traditional double-star architecture, the estimated near- and long-term costs for "POTS on Fiber" (POF) and for broadband-service provisioning are shown in Fig. 1. While today's costs for providing digital-loop carrier-based POTS are approximately $1,500 per customer using metallic wire pairs for the customer drop and $3,000 using fiber, the estimated costs of POF in the mid-1990s will approach those of today's metallic-pair costs. In addition, significantly lower costs-per-customer can be realized by providing, for example, "Fiber-to-the-Curb" access only, with wire pairs completing the connection to the customer.

Alternatively, cost savings may be incurred if some of the transmission equipment is shared among several customers through special fiber deployment schemes—such as a bus-star architecture with cost-effective multiplexing and/or time-division multiple-access protocols. Using such schemes, the per-subscriber costs for POTS service already can approach those of copper-based systems. It should be recognized, though, that some of the proposed low-cost deployment schemes may be more costly to upgrade to broadband than conventional subscriber loop architecture approaches. Consequently, careful consideration has to be given to the longer-range purpose of a particular installation.

As can be seen in Fig. 1, while

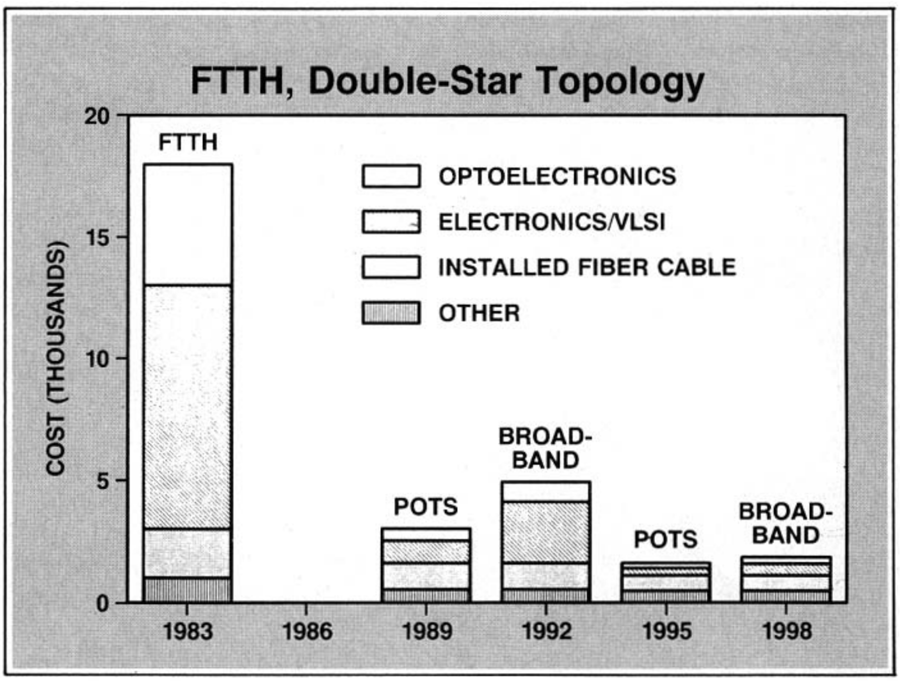

FIGURE 1. Broadband and POTS costs per subscriber vs. time (in 1000 $s).

broadband systems costs in the early 1990s are estimated to be still about twice as high as today's POF costs, this difference is expected to gradually disappear in the latter part of the decade when large-scale deployment of BISDN is expected to be well underway.

Since equipment costs are highly sensitive to production volume, it is of interest to try to predict the number of BISDN customer connections—and thus production volumes of related Central Office, Remote Terminal, and Customer Equipment—versus time. Using the so-called Fisher-Pry technology substitution model with the present FTTH introduction pattern as a base,[7] a Bellcore study estimates that a few million homes could receive broadband services by the year 2000, and there could be a 50% conversion to BISDN in the year 2010 (Fig. 2). The upper and lower bounds of the estimated BISDN connections reflect more optimistic and pessimistic assumptions, respectively.

It should be noted that the above predictions are sensitive to governmental and regulatory conditions, as well as the ambiguities of service acceptance in the marketplace. The introduction rate could potentially be faster for more favorable regulatory conditions regarding, for example, video distribution services.

Selected Fiber-to-the Home projects

While most of today's FTTH trials employ single-mode fibers (SMFs) and lasers operating in the 1300 nm wavelength region, some still use easier-to-handle multimode fiber technology. However, significant progress has been made in the cost-reduction of SMF technology, which is compatible with the bit rates of the evolving BISDN systems. Also, while the standard SMFs operate in the multimode domain in the 800 nm region, this wavelength band, nevertheless, can be used for very-low-cost transmission at moderate bit rates and distances (up to about 150 Mb/s.km).

TV distribution is accomplished using digital or analog modulation, as well as switched and broadcast transmission schemes. Amplitude-modulated (AM) and frequency-modulated (FM) sub-carrier multiplexing (SCM) techniques have recently found increased interest for video transmission on fiber because of the availability of these technologies at low cost.[8] However, there are critical optical device performance requirements for some of these applications, such as laser linearity and high-speed performance, as well as connector reflections, which challenge the most advanced optical device and systems technologies. On the other hand, digital modulation, including video codecs, eventually is expected to become cost-competitive with analog/SCM technologies for large-volume production. POTS and data transmission in FTTH installations is generally accomplished with conventional narrow-band technologies adapted for transmission on fiber.

Some of the more notable early FTTH installations are briefly summarized below. While highlighting special features, it should be noted that the summaries do not include all technology and service aspects of a particular installation (see also Table 1):

Hunter's Creek

At Southern Bell's Hunter's Creek near Orlando, the earliest U.S. FTTH test bed, a star architecture implemented by AT&T provides two 45 Mb/s standard (NTSC) TV signals (out of 36) on two multimode fibers to customers—thus representing the first digital video distribution system. In addition to 251 homes presently served on fiber, 166 homes are served on coaxial cable. One of the notable features of the Hunter's Creek Project is the reliable and high-quality digital video service that finds a high degree of customer acceptance. Evaluation of this trial continues with regard to the performance of the technology and customer usage patterns.

Heathrow

The Heathrow trial, also performed by Southern Bell near Orlando, involves a star network architecture for the combined transport of POTS, ISDN, and video services on two single-mode fibers. As part of this trial, Northern Telecom International will connect a total of about 3,200 homes by the early 1990s. The project includes, for the first time, residential ISDN services using 5.12 mb/s transmission in the 890 and 780 nm wavelengths regions for the downstream and upstream directions, respectively, using Northern Telecom's DMS100 switching system.

Up to four CATV channels (selecta-

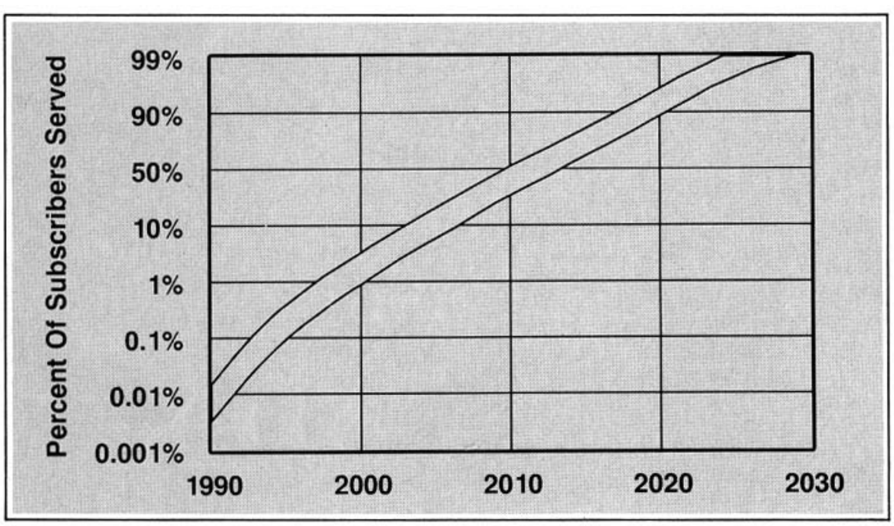

FIGURE 2. Possible growth of BISDN connections.

Table 1. OTC Fiber In The Loop Installations

TELEPHONE COMPANY	LOCATION	SUPPLIER	DATE OF FIRST SERVICE	NUMBER OF HOMES (INITIAL)	(FINAL)	SERVICES
Southern Bell	Hunters Creek, Fla.	AT&T	11/12/86	95	251	CATV transport
Southern Bell	Heathrow, Fla.	NTI	6/30/88	256	4000	POTS, ISDN, CATV transport
New Jersey Bell	Princeton Gate, N.J.	AT&T	8/9/88.	51	104	POTS, data
Southwestern Bell	Leawood, Kan.	AT&T	10/27/88	64	134	POTS
South Central Bell	Memphis, Tenn.	AT&T	11/16/88	43	99	POTS
Contel	Ridgecrest, Calif.	AT&T	12/28/88	100	400	POTS
Bell of Pennsylvania	Perryopolis, Pa.	Alcatel	1/25/89	80	100	POTS, CATV transport
US WEST	Mendota Heights, Minn.	AT&T	2Q89	100	—	POTS
Contel	Sidney, N.Y.	AT&T	2Q89	—	600	POTS
GTE	Cerritos, Calif.	ALS AT&T GTE	2Q89	100 600 5	5000	POTS, CATV and advanced broadband services transport
Southern Bell	Coco Plum, Fla.	AT&T	3Q89	12	200	POTS
Southern Bell	Governors Island, N.C.	AT&T	3Q89	4–8	49	POTS
Southwestern Bell	Mira Vista, Texas	ALS	3Q89	80	100	POTS, CATV transport
New England Telephone	Lynnfield, Mass.	Raynet	4Q89	100	100	POTS
Ameritech	(to be determined)	Raynet	(to be determined)	—	100	POTS
Southern Bell	Savannah, Ga.	AT&T	3Q89	—	192	POTS
Southern Bell	Charleston, S.C.	AT&T	3Q89	—	100	POTS
Southern Bell	Hunter's Creek, Fla.	AT&T	3Q89	—	100	POTS
U S WEST	Scottsdale, Ariz.	AT&T	4Q89	—	96	POTS
Southern Bell	Morrocroft, N.C.	AT&T	1Q90	—	126	POTS
Southern Bell	Columbia, S.C.	AT&T	1Q90	—	100+	POTS

ble from 64 offered) are simultaneously transmitted at 1300 nm within a 435 Mb/s downstream channel. Channel selection is performed with a 5.12 Mb/s upstream control signal (also operating at 1300 nm). The inclusion of HDTV as part of the services offerings is being studied. It should be noted that the Heathrow trial will also include business and commercial customers and will explore the possibility of "telecommuting".

Princeton Gate

New Jersey Bell's Princeton Gate installation in New Brunswick, N.J., is one of several OTC installations using an AT&T product, the Fiber-to-the-Home feature of the SLC® Series-5 carrier system. This system provides POTS and data services on single-mode fiber via a double-star architecture. Other AT&T installations listed in Table 1 use the same technology.

Perryopolis

In Perryopolis, Penn., Bell of Pennsylvania is offering POTS and CATV service with multimode-fiber/LED technology supplied by Alcatel. Out of a total 90 subscribers, 60 will receive both POTS and CATV service, and 30 POTS service only. In this trial, two video channels are subcarrier multiplexed, with one as an AM vestigial sideband signal at 38.9 MHz and the other as an FM signal at 20.7

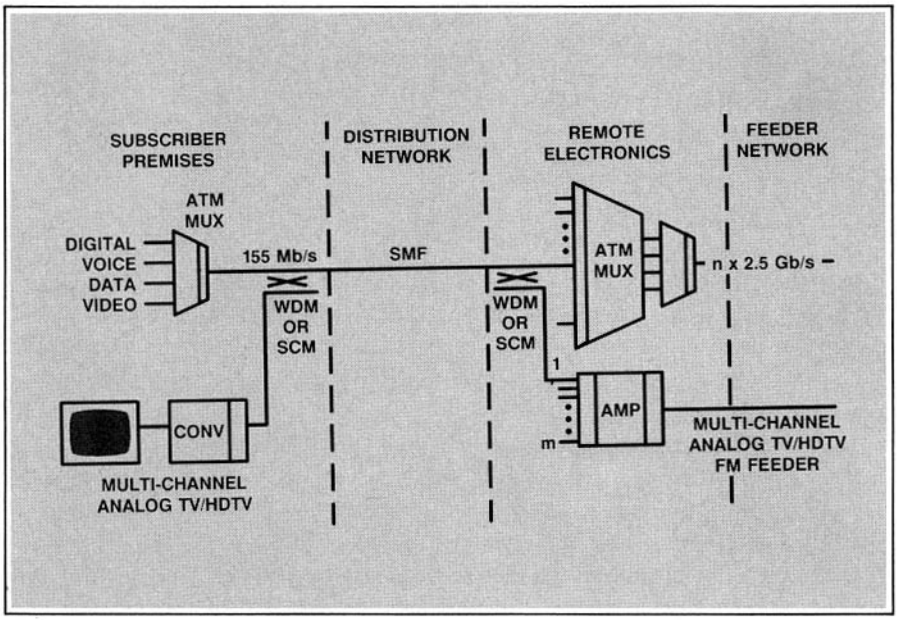

FIGURE 3. Schematic of Broadband Integrated Services Digital Network (BISDN) with analog overlay.

MHz. Voice, data, and signaling are subcarrier-multiplexed below 10 MHz. Perryopolis is the first location where POTS and CATV were offered on fiber simultaneously.

Cerritos

In Cerritos, Calif., GTE is installing a CATV system for up to 5,000 customers using both optical fiber and coaxial cable. Some of the fibers carry POTS as well as broadcast and switched video for 28 channels of Pay-Per-View programming. For a Video-on-Demand trial service to five customers, GTE is planning to provide 20 sumultaneous digital video channels using subcarrier multiplexing techniques on fiber (in the 2 to 6 GHz frequency band). One digital video channel originates from the home using a VCR or Camcorder as a source.

Mira Vista

In the Mira Vista community of Forth Worth, Texas, Southwestern Bell, in cooperation with American Lightwave Systems, supplies about 100 homes with four analog FM video channels (out of a total of 61 channels offered) and two digital voice channels. Both voice and video services are subcarrier-multiplexed in a 200 MHz signal. The voice capabilities include both standard POTS and narrow-band ISDN services. The trial offers Impulse-pay-per-view and is compatible with stereo and HDTV transmission. The upstream signal (on a separate fiber) carries two digital voice channels.

Lynnfield

New England Telephone will be the first to test the Raynet FTTH system in Lynnfield, Mass. To reduce initial costs, this LAN-like shared architecture multiplexes 192 POTS channels onto a single downstream fiber. At curbside locations, optical power is passively tapped, detected, and demultiplexed, and POTS signals converted to analog to be carried over wire pairs to the home. For upstream traffic, the reverse process is carried out over a second fiber.

Standards issues

Despite the use of manufacturer-specific technology, early FTTH installations represent an important step toward the introduction of fiber into the subscriber loop. However, the large-scale deployment of fiber in the subscriber loop and the cost-effective introduction of a broad range of new services depends critically on the existence of suitable network and interface standards. Such standards are required both at the transport level and for user access.

Based on the synchronous optical network (SONET) concept originally proposed by Bellcore and on work performed in the T1 Standards Committee in the United States, the International Telegraph & Telephone Consultative Committee (CCITT) adopted a set of bit rates for a new synchronous digital hierarchy (SDH) for transmission on single-mode fiber. The lowest SDH rate is 155.52 Mb/s (STM-1, or Synchronous Transmission Multiplex Level 1), followed by 622.08 Mb/s (STM-4) and 2.488 Gb/s (STM-16) obtained by simple, byte-interleaved multiplexing. (The probable next higher SDH level of approximately 10 Gb/s, or STM-64, has yet to be standardized.) In the United States, the 51.84 Mb/s SONET rate carries the 45 Mb/s DS3 rate of the North American digital hierarchy. The SONET concept allows cost-effective add-drop multiplexing and facilitates the interworking of equipment from different manufacturers with significant cost benefits for the customers.

In June 1989, CCITT Study Group XVIII reached a significant agreement on a standardized customer access to the future fiber network using the Asynchronous Transfer Mode (ATM). ATM involves the packet-like transmission of fixed-length cells (with a 48 byte—or octed—information field, and a 5 byte header) and allows the integrated transmission of a flexible mixture of different types of services over the same interface ("Bandwidth-on-Demand").

The schematic of a double-star local access network based on ATM multiplexing is shown in the top portion of Fig. 3: In the Central Office, digital signals belonging to a variety of service offerings are merged into

155 Mb/s bit streams that can be synchronously multiplexed into 2.5 Gb/s feeder signals for transmission to a Remote Terminal (RT). At the RT, data streams from demultiplexed 155 Mb/s signals are merged to conform to the service requirements of a particular end-user.

Services contained in the 155 Mb/s data streams may include, for example, a flexible combination of 16Kb/s meter reading and home monitoring data, 64 kb/s voice channels, 1.544 Mb/s data, and one or more 45 Mb/s data or NTSC video signals. A 155 Mb/s data stream may contain an HDTV signal encoded around 130 Mb/s. Up to four HDTV video signals, multiplexed together with other services, may be transmitted to a customer at 622 Mb/s. It should be noted that data rates on the order of 150 and 600 Mb/s have previously been identified as optimum rates of the provision of broadband services to end users.[1–4]

Future developments

With recent standards agreements as a guide, manufacturers have begun to develop BISDN prototype systems, with commercial SONET/ATM-based products expected to become available in the early 1990s (see, for example, Ref. 9). One of the early services leading to BISDN is the so-called Switched Multimegabit Data Service, or SMDS, which will provide a connectionless packet service initially at access rates of 1.5 and 45 Mb/s, and later on at 155 Mb/s. SMDS will also be available in the early 1990s and is expected to be used for Local Area Network interconnections.

To develop a consensus of how best to introduce future broadband equipment in the networks of the OTCs, Bellcore issued a Request-for-Information (RFI) to the telecommunications manufacturing industry. A summary of the responses to this RFI will be discussed at an Industry Forum to be held this month and will be made available as a Special Report.

It can be anticipated that some of the near-term FTTH technologies and associated services may be well established and cost-effective so that they continue to be used along with future standard BISDN technologies and services. Examples of this kind may be the distribution of multi-channel analog video signals via subcarrier multiplexing (SCM). As shown in the bottom half of Fig. 3, multiple broadcast channels—either analog or digital—can be overlaid compatibly on a BISDN system using either subcarrier-multiplexing or wavelength-division multiplexing techniques. In part, this became possible due to recent progress in the development of high-speed lasers. The SCM/WDM approach is attractive since it can be used to relieve network elements such as switches and multiplexers of the need to deal with long-holding-time video traffic and channel-change loads, among others.

Future network planners will also have to consider new technology developments such as dense wavelength-division multiplexing and coherent transmission techniques for the transport of large numbers of signal channels that can have different modulation formats. The increasing availability of precise wavelength-controlled and tunable lasers, tunable filters, optical amplifiers, and related technologies, for example, will permit the implementation of the so-called "Passive Photonic Loop" concept,[10] in which active, field-deployed multiplexing electronics is replaced by passive WDM components (Fig. 4). Individual subscribers are assigned unique or shared wavelengths for up and downstream transmission. This and other passive loop approaches, such as British Telecom's "Telephony Passive Optical Network" (TPON)[11] are receiving increased attention since they reduce powering requirements, improve the reliability of the local network, and typically are readily upgradable to higher bit rates.

The ultimate implications of the FTTH concept in laying the foundation for the new "Information Age" are far-reaching and can only be imagined at this time.

Many researchers and technologists have dreamed of using optical fiber with its low loss and immense bandwidth for improving the capability and productivity of businesses, and the quality and enjoyment of people's lives. "Fiber-to-the-Home" appears to be the rallying cry for making this dream a reality by mobilizing virtually all segments of society.

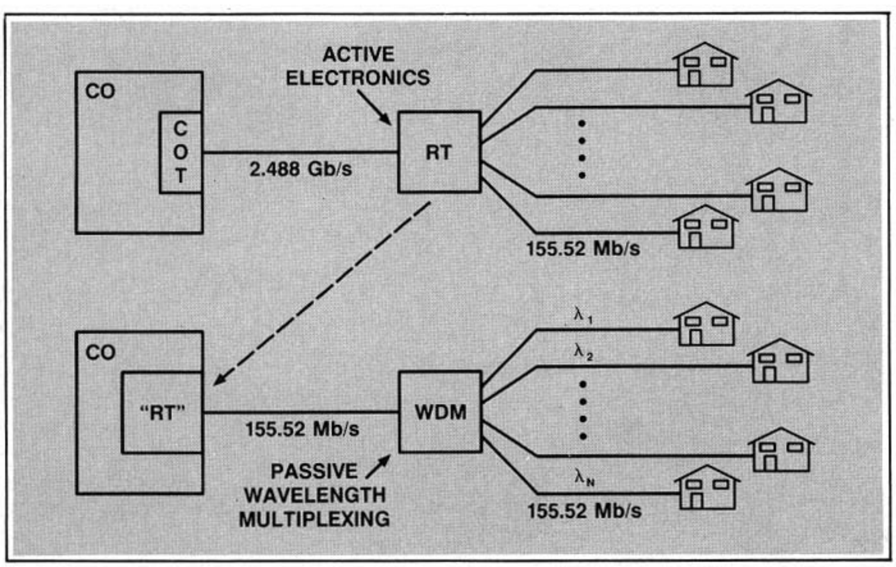

FIGURE 4. Principle of passive photonic loop (CO: Central Office; COT: Central Office Terminal; RT: Remote Terminal).

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