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Original Paper

Prototype of end-to-end optoelectronic conversion terminals for telecommunications systems up to 25 km

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Abstract

Optical fiber is one of the most widely used media in telecommunications systems due to its greater resistance to electromagnetic interference, lower attenuation over distance and higher bandwidth and transmission speed capabilities. This paper presents the results of designing and constructing a prototype that uses single-mode optical fiber as the communication medium to extend the connection between network equipment and user terminals, given that most user terminal equipment uses Ethernet ports and therefore relies on twisted-pair copper cables for interconnections, which are well known to be limited in terms of attenuation and interference. The system uses media converters that are compatible with Fast and Gigabit Ethernet standards. They feature auto-negotiation speeds and SC/FC UPC optical ports. They also use ITU-T G.652D single-mode fiber with a range of up to 25 km and an electronic fan cooler. All of these components are encapsulated in a plastic mechanical housing. Tests using optical fiber reels established the required distances, achieving transmission with latency below 5 ms, optical attenuation of less than 0.22 dB/km and zero packet loss at 1550 nm.

Keywords: optical fiber, single-mode, conversion, Fast Ethernet, Gigabit Ethernet

1. Introduction

Data transmission in local area networks has traditionally relied on unshielded twisted-pair (UTP) copper cabling in accordance with Ethernet standards. However, this medium has significant physical limitations; the maximum effective distance before attenuation and electromagnetic interference degrade the signal is 100 metres (ANSI/TIA-568.2-D, 2018). Optical fiber offer substantial advantages over copper. Firstly, they have extremely low attenuation (typically 0.22 dB/km in single-mode fiber at 1550 nm), enabling signals to travel tens of kilometers without repeaters (ITU-T G.652, 2016). Secondly, as a dielectric medium, fiber is completely immune to electromagnetic interference, which is crucial in industrial environments or near high-voltage power lines. Furthermore, fiber does not emit electromagnetic signals outwardly, which makes unauthorized interception difficult and improves security. To reap these benefits without replacing existing network cards (which are usually copper-based Ethernet), optoelectronic media converters are employed. These devices convert the UTP electrical signal into an optical signal for fiber transmission and viceversa. They integrate an electrical transceiver (PHY) for the RJ-45 port, a laser diode or LED for optical transmission, a photodetector for reception and conditioning circuitry internally. They operate transparently to higher-layer protocols without modifying Ethernet frames or requiring IP address configuration (IEEE 802.3-2018). Special solutions have previously been developed (e.g. Cárdenas et al., 2006), and bed tests have been conducted to evaluate devices (e.g. Pincemin et al., 2023). The proposed solution is tailored to a real-world transmission environment with defined specifications; therefore, the goal is to propose a solution that can be adapted to different end-user requirements using commercially available devices. In the context of Ethernet, two speed variants are relevant: Fast Ethernet (IEEE 802.3u), which operates at 100 Mbps using two copper pairs or multimode fiber, and Gigabit Ethernet (IEEE 802.3ab), which reaches 1000 Mbps (1 Gbps) over four copper pairs (1000BASE-T) or optical fiber (1000BASE-SX/LX). The converters used are auto-negotiating and can automatically detect the maximum speed supported by the connected devices.

2. Methodology

2.1 Block Diagram

The system block diagram (Figure 1) consists of two identical terminals, labeled A and B. Each terminal contains a 4-pin terminal block which distributes the 120 VAC, 60 Hz wall outlet type B power supply to two DC power sources, the outputs of which are 5 VDC and 12 VDC respectively. The 5 VDC source powers the media converters and the 12 VDC source powers a cooling fan. The media converter has four UTP ports (RJ-45 Cat6) for connecting user equipment (up to 100 meters per port) and four SC optical ports for ITU-T G.652.D single-mode fiber (range up to 25 kilometers). Both terminals are interconnected via four-wire drop-type optical fiber reels of up to 4 km and 1 km each with FC/UPC connectors. The system operates in auto-negotiation mode at speeds of 10/100/1000 Mbps. Each terminal is enclosed in an ABS enclosure.

2.2 Prototype Components

Table 1 lists the components used, based on the design documented in the prototype drawings.

2.3 Construction of the prototype

The prototype was built at the Cendit Foundation's (Figure 2) in the following steps:

1 Preparation of the housings: Holes were drilled in each ABS housing in order to mount the RJ-45 connectors, the female SC/FC adapters, the fan and the terminal blocks.

2 Converter assembly: The four media converters were secured inside each housing, leaving space for wiring and airflow.

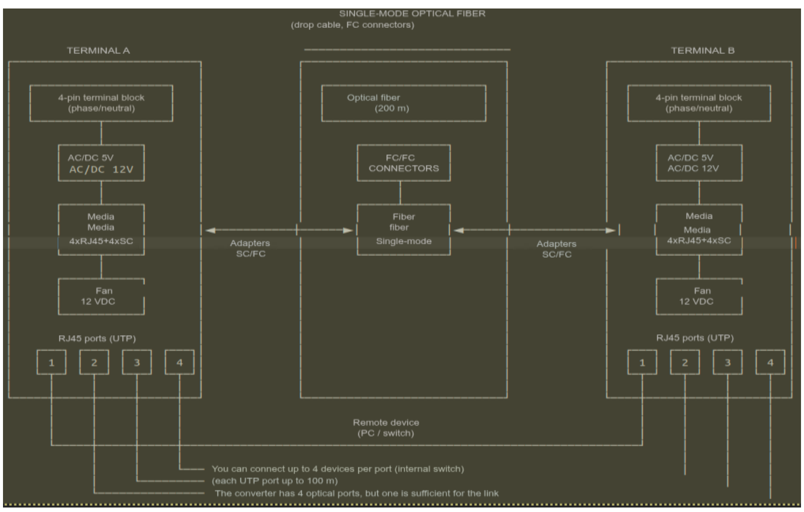

Figure 1. Block diagram of prototype

Table 1. Prototype Components

Component	Qty	Specifications
Optoelectronic converters	8	10/100/1000 Mbps auto-negotiation, 4 Cat6 UTP RJ45 ports, 4 SC optical ports (SM), 25km range, 850/1310/1550nm
5 VDC power supply	8	Input 120 VAC, output 5 VDC / 2 A
12 VDC power supply	2	120 VAC input, 12 VDC / 3.6 A output
4-pin terminal block	2	Phase and neutral distribution
Fiber-optic reels G.652.D (4 km)	6	Single-mode 9/125 µm drop type, 4-strand, FC/UPC connectors, 4 km length
Fiber-optic reels G.652.D (1 km)	1	Single-mode 9/125 µm drop cable, 4-strand, FC/UPC connectors, length 1 km
UTP cable	8	Category 6, 2 m each, RJ45
AWG power cable	8	Multi-strand, phase and neutral
ABS housing	2	Dimensions 26.5×7×20 cm (NAP was used)
Fan (fan-cooler)	2	12 VDC, 1 A

3 Power wiring: The 5 V (to converters) and 12 V (to fans) power supplies were connected to the 4-pin terminal block to distribute phase and neutral.

4 Cooling system: A 12 V fan was installed on one side of each enclosure and was oriented to exhaust hot air; there were intake vents on the opposite side.

5 Signal connections: Internal UTP ports (short cables) connected the converters to the RJ-45 connectors mounted on the enclosure. The SC optical ports were also connected using short, drop-type optical fiber with SC quick-connect optical connectors.

6 Continuity and insulation testing: The continuity of the electrical connections was measured using a multimeter to verify that there were no short circuits between the phase and neutral.

Figure 2. Picture of prototype

3. Result

3.1 Experimental Setup

Single-mode, drop-type optical fiber on reels were interconnected, with a converter terminal placed at each end. A server (a PC with a Gigabit Ethernet port) was connected to Terminal A's UTP input, while a client computer was connected to Terminal B's UTP output. The AC/DC power supplies were connected to the 120 VAC, 60 Hz mains via terminal blocks. The setup is shown in Figure 3. The optical link reachs 25 km.

Figure 3.

3.2 Connectivity and Performance Tests

1. Ping test: to measure average latency and packet loss.
2. Optical power measurement: to measure the received power for wavelengths 1310/1550 nm.
3. Speed test: An Internet speed test was performed using the ISP's application.

4. Discussion

The evaluation shows that the optoelectronic converter terminal prototype reliably extends Ethernet networks over long distances. A packet loss rate of 0%, together with latency below 5 ms, confirms high network stability. The optical power attenuation measurements (0.32 dB/km at 1310 nm and 0.21 dB/km at 1550 nm) strictly adhere to the ITU-T G.652 standards for single-mode fibre. The speed test result of over 800 Mbps shows that commercial media converters can maintain effective throughput without affecting the ISP's service. Furthermore, the active cooling system was essential for maintaining safe operating temperatures within the ABS NAP housing during continuous operation.

Table 2. Test Results

Test Parameter	Measured Value	Expected Value
Packet loss (100 packets)	0,00 %	0,00 %
Received power at 1310 nm (A→B)	-12.72 dBm	-12,6 dBm
Received power at 1310 nm (B→A)	-11.87 dBm	-11,75 dBm
Received power at 1550 nm (A→B)	-9.46 dBm	-9.35 dBm
Received power at 1550 nm (B→A)	-8.48 dBm	-8.40 dBm
Download speed	982 Mbps	1000 Mbps
Upload speed	855 Mbps	1000 Mbps
Latency (ping to ISP server)	4,20 ms	4 ms

5. Conclusion

A prototype of optoelectronic converter terminals has been successfully designed, built and validated to extend Ethernet networks by up to 25 km using single-mode optical fiber. The prototype establishes a functional link of up to 25 km with 0% packet loss, latency of less than 5 ms and an effective bandwidth exceeding 800 Mbps. Optical power measurements at 1310 nm and 1550 nm showed attenuation of 0.32 dB/km and 0.21 dB/km respectively, which is fully within the ITU-T G.652

standard. This replicable, low-cost solution utilizes commercial components and can be applied in multiple scenarios, including industrial, educational, government and university campus environments. Future developments will include integrating PoE to eliminate the need for external power sources at the remote end.

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