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DEVELOPMENT OF WDM OPTICAL TRANSMISSION SYSTEM OVER GI-POF PAIR CABLE FOR TELEVISION RF, GIGABIT-ETHERNET, AND HDMI/DVI

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Abstract: Various metal cables are used in a house: such as Unshielded Twist Pair (UTP) cable for Gigabits Ethernet (GE), High Definition Media Interface (HDMI) for high definition (HD) video contents, and coaxial cable for TV broadcast. To reduce its complexity for consumers, we successfully developed wavelength division multiplexing (WDM) transmission system over Graded-Index Plastic Optical Fiber (GI-POF) pair cable to replace these complex metal cables. This system consists of newly developed E/O-O/E converters for each media signal and multi-wavelength Multiplexer (MUX) and De-Multiplexer (DEMUX). Almost all GI-POF wiring for a local area network in home, campus, hospital, and factory can be achieved. Such WDM-GI-POF wiring in the premises can make simple, smart and safe multimedia network services without increasing the number of cables.

Key words: GI-POF, WDM, TV-RF over GI-POF, MUX/DEMUX, home network.

1. Introduction

Intelligent home network has been using three different kinds of wiring: (1) Unshielded Twist Pair (UTP) cable for Gigabits Ethernet (GE) data communications, (2) High Definition Media Interface (HDMI) for the interconnection between HD-Camera, HD-recorder/player, and HD-display, and (3) coaxial cable for various broadcast-TV/CATV. These metal cables have disadvantages such as the limits of transmission distance and unfavorable physical characteristics (hard, thick and heavy).

Therefore, media converters from electric to optical were developed to overcome these problems. Previously, we have proposed an HDMI media converter for GI-POF "HDV-OTR"[1] and a media converter for Television Radio Frequency (TV-RF) over GI-POF "FTV-T/R"[2]. Media converters for Gigabits Ethernet and HDMI are now commercially available. Since different wavelength light sources for above three kinds of media converter can be allocated, one GI-POF can carry all three media using the wavelength division multiplexing (WDM) optical transmission method. A smart GI-POF wiring are expected to deliver all media at home [3].

In this paper, improved E/O and O/E converters for TV-RF over GI-POF are proposed, which have newly developed 4-ports multiplexer (MUX) and De-multiplexer (DEMUX). Its development and demonstration using WDM transmission systems over GI-POF pair cable are discussed. The system can replace all three types of metal cables with GI-POF: coaxial cables for TV, UTP cables for GE, and HDMI cables for real time high definition video. Almost all GI-POF wiring in the premises realizes enjoyable entertainment, smart working environment, and face to face communications.

2. Proposed intelligent home network over a GI-POF

Recently, FTTH has come into wide use and its optical network unit (ONU) is placed near the wall in house. Gigabits Ethernet and Television broadcast, especially for "FLET's TV" in Japan served by Nippon Telegraph and Telephone Corporation (NTT), deriver contents to PCs or TV-displays through different metal cables: UTP or coaxial cables. Watching HD cameras nearby porch or at some rooms are connecting to the monitor HD display at living room by HDMI cables for fine and real time view. All these cables are still using metal cables at present and have the transmission distance limit and not easy handling for thick and hard metal cables. We have proposed replacing these metal cables with GI-POF which is easy for handling, flexibility, and possible low-cost, simple interconnection. A scene of proposed intelligent home network over GI-POF is shown in Fig.1.

For Gigabit Ethernet, we have its commercially available media converters with 850nm or 1310nm, which are applicable to GI-POF pair cable. For HDMI, we have developed HDMI/DVI media converters, "HDV-OTR"[1], which are using 4-wavelength between 780nm and 980nm. For TV-RF over GI-POF, we have now E/O and O/E converters using 670nm or 810nm-VCSELs. Under these conditions, we have chosen the wavelength of GI-POF

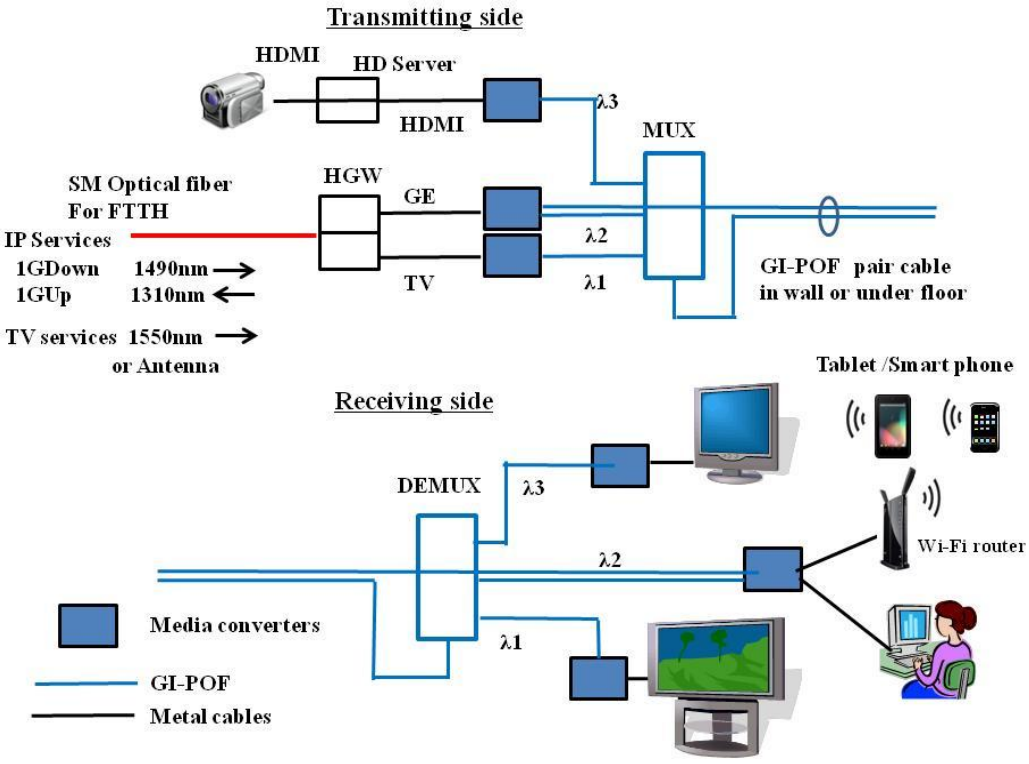

Fig.1. A scene of proposed intelligent home network over a GI-POF

WDM transmission, which are 670nm band (λ1) for TV-RF over Fiber, 780nm-980nm band (λ3) for HDMI, and 1310nm-band (λ2) for Gigabit Ethernet, respectively, and then we decided to develop 4-ports MUX/DEMUX with λ1-port, λ2-port, λ3-port, and the common port. At the transmitting side, three different wavelength lights from three media converters for GI-POFs are multiplexed into a GI-POF cable in a pair GI-POF cable, and at the receiving side these lights are de-multiplexed and delivered to the corresponding media converters with HD-display for watching TV-broadcast, HD-display for watching HD-camera video and PC or Wi-Fi access router for data communications. Since our available GE-media converters need a pair cable, we should use a pair GI-POF cable. In this paper, we demonstrated that one pair GI-POF cable can deliver all media up to the end devices without increasing the number of cables.

3. E/O and O/E converters for TV-RF over GI-POF transmission system

Newly developed E/O and O/E converters for TV-RF over GI-POF are shown in Fig.2. To improve their performance from the previously reported paper[2], the VCSELs were carefully selected with good linearity of the I-L characteristics, high intrinsic quantum efficiency, high coupling efficiency between the VCSEL and GI-POF through SC connector, and the narrow optical spectral width. Furthermore, an adjustable RF input signal attenuator switch with 1dB-step is added to optimize the modulation amplitude for the VCSEL and to increase RF input level margin for E/O converters. The selected VCSELs had 670nm-band and 810nm-band.

For O/E converters, we firstly used GaAs-PIN PD and the trans-impedance amplifier IC which is commonly used for digital circuits [2]. Since the trans-impedance amplifier has usually large gain and limiting amplitude circuit, the linearly operating amplitude range is limited. This time, we have used GaAs-PIN PD and two stage-broard band amplifier with 30dB-gain and successfully obtained better performance up to 2.1 GHz.

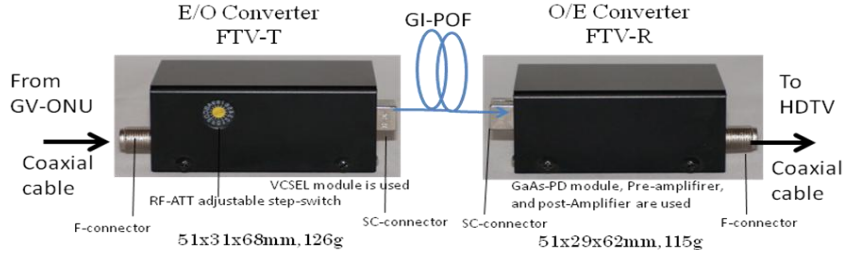

Fig.2. Newly developed E/O Converter (FTV-T) and O/E Converter (FTV-R) for TV-RF over GI-POF system

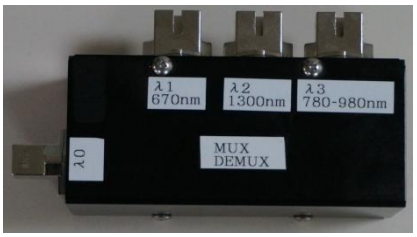

Fig.3. 4-port multiplexer/de-multiplexer (MUX/DEMUX) for GI-POF (Size 90mmx42mmx41mm)

TV-RF over GI-POF transmission system with developed E/O and O/E converters has worked well for all television services including FM radio, analog-TV converted from terrestrial digital TV ("Digi-Ana"), terrestrial digital TV (TD), digital TV from broadcasting satellite (BS), and additional service TV from communication satellite (CS) and Sky PerfecTV[4] through NTT- FTTH services "FLET'S TV." For all television services the bit-error-rate (BER) is kept to be zero, which is measured by RF-checker 2[5]. In this measurement, the transmission distance up to 50m for GI-POF with the core diameter of 55μm and 120μm has been investigated and achieved with the zero error-rate for all television services in Japan.

During operation, the small noise sometimes occurs and the signal to noise ratio decreases due to the local oscillation at the local external cavity between the 810nm-band VCSEL with relatively high efficiency and the end of SC connector for O/E converter. Such noise occurrence depends on the light reflection at the end of SC connector to GaAs-PIN PD. The angled polished end of SC connector can effectively works to decrease such noise. Fortunately, the 670nm-band VCSEL does not usually have such noise. Therefore, E/O converters with 670nm-band VCSELs are better used for WDM-GI-POF systems with many connectors for the interconnection.

4. Multiplexer and de-multiplexer for WDM-GI-POF systems

We developed 4-port multiplexer/de-multiplexer (MUX/DEMUX) with 670nm-port for TV-RF over GI-POF, 1310nm-port for Gigabits-Ethernet media converters (GE-MC), 780-980nm-port for real time HD video transmission, and the common wavelength-port, as shown in Fig.3.

This 4-port-MUX/DEMUX has thin film filters for each port. The outputs of 670nm-FTV-T, 1310nm-GE-MC and 780-980nm HDV-OTR are multiplexed at the transmitting side and de-multiplexed at receiving side by the 4-port MUX/DEMUX and the interconnection of GI-POF for the long distance is connected by common ports. TV-RF over GI-POF, Ethernet over GI-POF and HD-Video over GI-POF were simultaneously transmitted through the same GI-POF cable up to the de-multiplexer which derivers to TV, PC and HD-Display in a house.

Fig.4 shows the transmission of the developed MUX/DEMUX between the common port and three wavelength ports, which is estimated from the characteristics of the used thin film filters. The measured average transmission loss is less than 1dB at 670nm-port (λ1), 2dB at 1310nm-port (λ2), and 2.5dB at 780-980nm-port (λ3) for GI-POFs of both 55μm and 120μm core diameter. The transmission of 670nm (λ1) is the reflection light from long wavelength pass filter with the 45° incident angle. The transmission of 1310nm (λ2) is the reflection light from short wavelength pass filter with the 45° incident angle after an incident light passes through the first filter of λ1. The transmission of 780-980nm (λ3) is the reflection light from the mirror after an incident light passes through two filters of both λ1 and λ2.

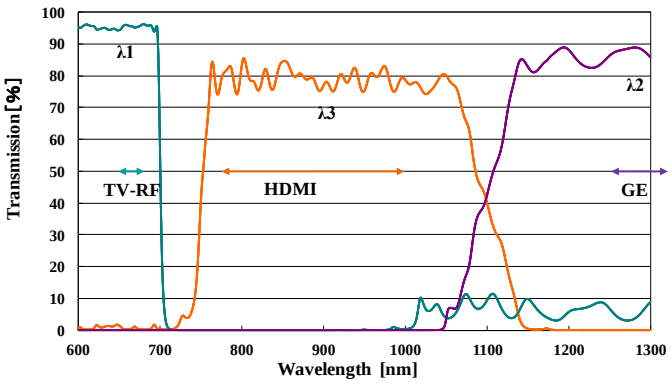

Fig.4. Transmission of the developed MUX/DEMUX between the common port and three wavelength ports

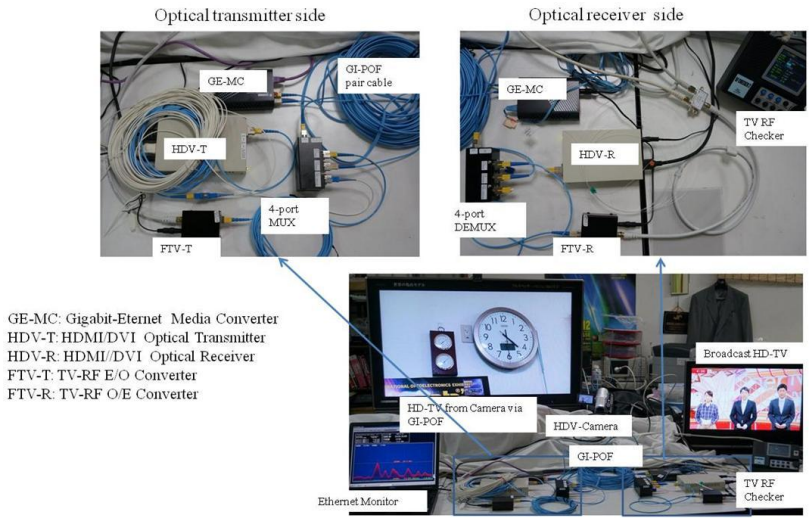

Fig.5. The experimental scene of WDM transmission of TV-RF, Internet, and HDMI/DVI media on one GI-POF pair cable

Next, all three media WDM transmission over GI-POFs in house as shown in Fig.1 has been investigated. For television broadcast, NTT offers FLET's TV services including FM radio, analog-TV converted from terrestrial digital TV ("Digi-Ana"), terrestrial digital TV (TD), digital TV from broadcasting satellite (BS), and additional service TV from communication satellite (CS) and Sky PerfecTV through NTT-FTTH services. As other TV services, there are TV broadcasts with TD, BS, and CS through roof antenna, and CATV. Our developed E/O converter, FTV-T can converts all these TV radio frequency microwaves to the optical waves on GI-POFs. For watching nearby porch or the other rooms, HD cameras with HDMI outputs have been used. For entertainments, HD-players and servers with HDMI outputs are often used. HDMI transmission has a merit of real time HD video transmission including full HD video and 3D/4K.

HDMI converters for these media convert to the optical signals on GI-POFs. For internet, FTTH services have Gigabits Ethernet port in house and the GE converter convert it to the optical signal on GI-POF.

The experimental scene of WDM transmission of TV-RF, Internet, and HDMI/DVI media on one GI-POF pair cable is shown in Fig.5. Here, 50m-pair GI-POF is used for the interconnection between the common ports of MUX of the transmitting side and DEMUX of the receiving side. For example, this one pair GI-POF cable and MUX/DEMUX are installed in wall or under floor and connected one room to the other room. These media converters will be in one small board and put in each media transmitter at final stage. Inside the house, all media are interconnected smart GI-POF wiring, whose merits are extending transmission distance, no electrical magnetic disturbs, easy handling for curving, knotting, or standing on, and more secure than glass fibers.

5. Conclusions

We showed newly developed E/O and O/E converters for TV-RF over GI-POF and 4-port MUX/DEMUX for GI-POF. Furthermore, we demonstrated the WDM-GI-POF transmission systems of TV-RF, Internet, and HDMI/DVI media using these developed components. Smart houses of GI-POF wiring for every media without microwave coaxial cables and HDMI cables will be expected, likely to be nerve fibers in human body. Almost all GI-POF wiring for a local area network is applicable not only at home, but also in campus, hospital, and factory. Such WDM-GI-POF wiring in the premises can make simple, smart and safe multimedia network services without increasing the number of cables.

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