Power and Radio over DCF for

4k/8k Satellite Broadcasting System

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Abstract

With the increasing number of 4K/8K channels and the development of broadcasting technology, the frequency used for the intermediate frequency (IF) signal keeps increasing. However, using traditional cable transmission in processing causes serious signal loss. In the previous research of our Lab, it is proved that using fiber to replace cable can achieve lower signal loss and reduce the noise sensitivity by Radio-over-Fiber (RoF). In a general satellite broadcasting system, the antenna receives the signal from BS/CS with frequency around 12 GHz. The frequency used by 4K / 8K TV increases to 1032-3224 MHz [1]. But RoF also puts forward higher requirements for energy transmission.

Double-Clad Fiber (DCF) is a kind of optical fiber with three layers of optical material that can achieve Single-Mode and Multi- mode transmission simultaneously. DCF is a good option for combining the power transfer and signal transfer because the high-power light can be transmitted without effect the signal transfer. Over 10m, energy and signal are transmitted by the same DCF. It is proved that PoF is practicable to be used in the 4K / 8K Satellite Broadcasting System and the breakthrough is

combining RoF and PoF together in DCF.

1. Introduction

1.1. Background

Japan has a long history of cable TV distribution systems. Digital broadcasting over cable television began at about the same time as communications satellite (CS) digital broadcasting in 1996. Since then, various transmission schemes have been developed and commercialized [1]. Initially the industry chooses coaxial cables, but in recent years there have been supplemented by optical fiber.

The schematic of a general satellite broadcasting system is shown in Fig. 1. The antenna receives the signal from BS/CS which is with a frequency of around 12 GHz. The signal in this frequency is difficult to be transmitted and processed [2]. So, firstly the Radio Frequency (RF) signal is to be converted into the signal with a lower frequency called the intermediate frequency (IF). Then can it be transmitted to the Set-top Box (STB) to process. The most popular way currently is using cable for television services to transmit radio-frequency signals in the VHF and UHF bands. To compensate Fig. 1 Schematic of the Existing Satellite Broadcasting System or transmission losses in coaxial cable, amplifiers must be installed every few hundred meters. Large-scale cable facilities are transitioning to hybrid fiber coaxial (HFC)

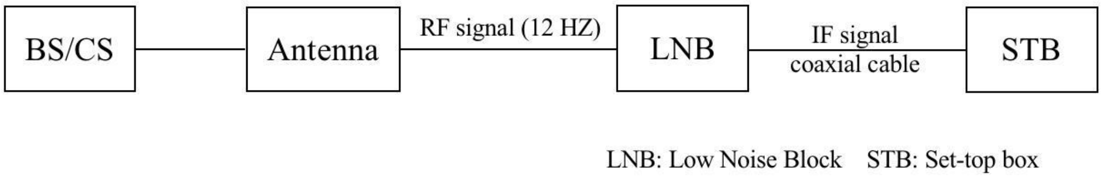

Fig. 1 Schematic of the Existing Satellite Broadcasting System

media, but most small-scale facilities are still using all-coax cable. In addition to the standard for transmission of digital radio wave broadcasts via cable, the medium used to transmit cable signals has also changed.

4K / 8K TV channels have been applied to market in recent years along with the development of satellite broadcasting technology. The 4K/8K satellite broadcasting featuring ultra-high-definition video and sound was launched in Japan. As shown in Fig. 2, as the first 8K ultra-high-definition television (UHDTV) broadcasting system in the world, the UHDTV system is with 16 times as many pixels as HDTV and 3D sound with 22.2 channel audio [4]. The large amount of information that must be transmitted, means that a new satellite broadcasting transmission system had to be developed.

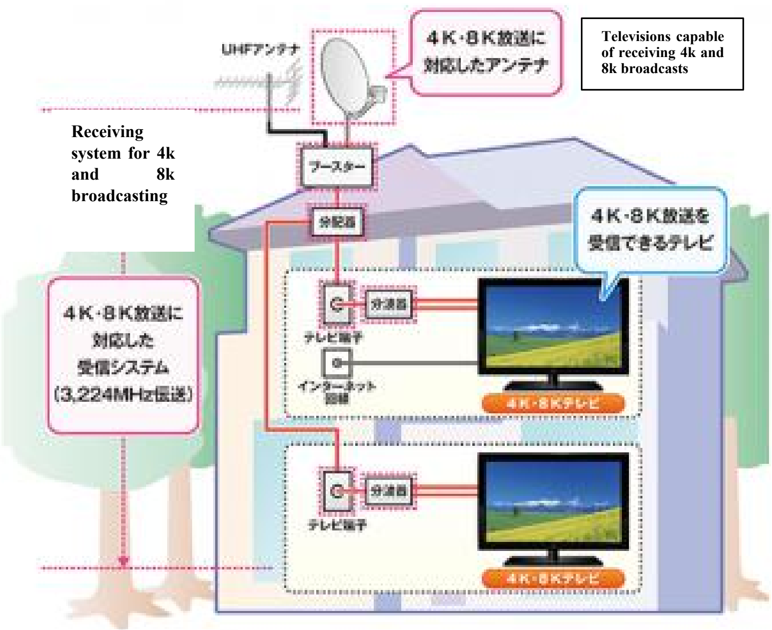

Fig.2 Home Broadcasting system of 4K/8K TV in Japan

It's objective that all cables have signal loss. The unit of measurement of loss is in power decibels (dB). The longer the cable, the greater the loss. Also, signal loss depends on frequency. The higher the frequency (the higher the RF channel), the greater the loss. RF channels in the VHF band have noticeably less loss than channels in the UHF band.

To watch 4K/8K TV channels, there is various work for viewers to do. Not only to replace the signal receiving/transmitting equipment such as boosters or distributors that support high-frequency signals transmission but also to dedicate the satellite antenna to receive signals. Even if all these preparatory works mentioned are completed, the viewer often still finds it hard to watch smoothly sometimes [3].

1.2. Related Works

There are several research that proves the accessibility of the advantage of applied Double Clad Fiber (DCF) in combining RoF and PoF.

Firstly, based on Radio over Fiber (RoF) technology, some studies have reported that the RoF technology has a great advantage in high-frequency signal transmission with low signal loss. Atsushi Kanno discussed an RoF technology used as a seamless conversion technique between optical signals and millimeter-wave signals, even terahertz-wave signals. They succeed in achieving low-latency, high-capacity, and high-performance fiber–wireless systems by using the RoF technology. Also, they have successfully demonstrated a simultaneous transmission of power and radio signals over a fiber system [5]. David Wake compared the cost and performance of RoF links for the application with alternative link types that use digitized radio transmission and showed that RoF is the optimum choice from a cost perspective. They pointed out that the performance of the radio over fiber links is shown to be acceptable using low-cost lasers and photodiodes [5]. Byung Gon Kim experimentally verified the IF-over-Fiber (IFoF) transmission scheme's practicality by using commercial base stations and deployed optical fibers. Their results showed that no significant degradation was observed under this realistic condition similar to commercial LTE systems [6].

The electrical supply lines outdoors may result in electrical safety problems. It is not convenient as well. So, the use of Power-over-Fiber (PoF) technology is one approach to solve these problems. Kensuke Ikeda proposed a system using PoF technology to protect microwave radio equipment from lightning. In their experiments, antenna side optical to electrical (O/E) and electric to optical (E/O) converters were worked by power over fibers. Results showed the proposed configuration can perform applicable communication quality [7]. Motoharu Matsuura introduced the PoF technology that can achieve power remote antenna units without any external power supply systems in RoF networks. He demonstrated that using double-clad fibers (DCF) is a possible solution to simultaneously do the signal transfer and power transfer inside one optical fiber. They have experimentally evaluated the signal performance of beam steering for a 60-W power-over-fiber feed using a 300-m double-clad fiber link in terms of error-vector magnitude measurements, and results show that the Power over Fiberenables optical fiber delivers more than 26 W of optical power with a power transmission efficiency of 44.5% [8].

In the formal work of our lab, by using an RoF transmission system, a low signal loss transmission method for the new 4K/8K satellite broadcasting system is proposed. The work has an excellent signal loss performance in high-frequency and long-distance signal transmission. Referring to the experiment results, it is proved in the experiment that in each frequency range, the proposed system clearly gives a better signal loss performance than the system using a coaxial cable. A 9.89 dB improvement of the average amplitude is achieved to transmit the IF signal at 2749-3224 MHz. Meanwhile, the optical fiber's advantages in attenuation ensure that the signal loss will not worsen when the maximum IF is increased higher than 3224 MHz in the future [3].

2. System of Power and Radio over Fiber

2.1. Fiber Optical Communication

2.1.1. Power over Fiber

Power-over-fiber (PoF) technique, i.e., the delivery of power through optical fiber, has developed many novel applications including sensors, endoscopic imaging, and illumination [4]. PoF is the ideal solution when there is a need for, as example, galvanic isolation, high voltage or lightning protection, electromagnetic interference, wireless transmission, weight reduction, spark protection, corrosion resistance, high magnetic fields, or rotating systems. Miller et al. demonstrated a bidirectional speech - television communication over a single optical fiber, with emergency optical powering of the remote station telephone [5]. Motoharu Matsuura introduced the PoF technology that can achieve powering remote antenna units without any external power supply systems in RoF networks [6].

Structurally, in a PoF system, the local control unit and the remote unit are connected by two optical fibers. The control unit is composed of the high - power optical source (HPOS) unit together with the optical reception unit (ORU), which receives signals from the remote sensor unit. The optical fibers can be standard SMF optical fibers or MMF. The classification of optical fiber of SMF and MMF will be detailed in the later section. In the remote unit, a photovoltaic converter detects the power transmitted by the HPOS. The electrical energy produced by the photovoltaic converter is used to power up a low‑threshold laser (LD), electronic circuits, and sensors of the remote unit. During practical application, there are many low-cost/low-power/high-efficiency electronic sensors available for transmission lines and substations monitoring that can be supplied by PoF. It eliminates the necessity of batteries, solar panels, and long cupper feeder wires in remote sites, improving the reliability and the security of the system [4]. In RoF networks, the use of PoF is effectively used to centralize the required power source in a central station (CS) and to deliver the feed light with optical data signals in the same cables [7]. The use of PoF permits the reduction of the space and the installation cost in remote sites, which is very important in a commercial application.

2.1.2. RF and Radio over Fiber (RoF)

Radio-over-Fiber (RoF) refers to the technology whereby light is modulated by a radio frequency (RF) signal and transmitted over an optical fiber link. In narrowband communication systems and WLANs, RF signal processing functions such as frequency up-conversion, carrier modulation, and multiplexing, are performed at the BS or the RAP, and immediately fed into the antenna. RoF makes it possible to centralize the RF signal processing functions in one shared location (headend), and then to use optical fiber, which offers low signal loss (0.3 dB/km for 1550 nm, and 0.5 dB/km for 1310 nm wavelengths) to distribute the RF signals to the RAUs [4]. RoF is commonly used in eliminating signal loss and increasing the range of communications.

A schematic of a general RoF system consists of an electric-to-optical (E/O) and an optical-to-electric(O/E) conversion device. The E/O device is where the light is modulated by the RF signal and the O/E device is for the radio signal recovered from the optical signal [2]. These two conversion devices are connected by an optical fiber. Compared with the radio signal transmission through the coaxial cable, the optical signal transmitted through an optical fiber achieves a remarkably low transmission loss, and the range of the transmission frequency is wider. Also, the frequency deviation is much smaller in the optical fiber. As there is no signal encoding and decoding process in a RoF system, it has no remarkable transmission delay. Therefore, the RoF system can easily achieve tens of kilometer transmission or high-frequency signal transmission with the low signal loss [3]. When adopting RoF technology into the broadcasting system, improvements can be made. In the previous research [2], the result shows that in each corresponding frequency range, the 4K/8K satellite antenna system using RoF gives a better signal loss performance than that using a coaxial cable. The RoF technology with a 50:50 signal splitter has a remarkable advantage in signal loss performance compared with the coaxial cable with an electrical 50:50 signal splitter. The output amplitude of the 50:50 electrical signal splitter is very low and close to the noise value, while the output of an optical signal splitter is still easy to achieve.

2.2. Double Clad Fiber

Optical fiber offers not only greater bandwidth over longer distances but also a better signal to noise ratio, greater immunity to interference and reduced size and weight. Through optical fiber, the transmission over longer distances without amplifiers is achievable. These better transmission characteristics and the elimination of amplifiers result in benefits such as lower failure rates and easier maintenance.

Rather than the signal loss in optical fiber, the maximum transmitted optical power is more of a major problem. When a high - power optical signal is propagated in the fiber, the energy absorbed by the coating in the zone of curvature is high, which causes a local increase in temperature at the coating [10]. To avoid the degradation caused by heating of the optical fiber coating, in this experiment, real-time monitoring of temperature change is necessary. A proper environment is conducive to prolong the useful life of the fiber. DCF helps to avoid various line repeat construction, seize the

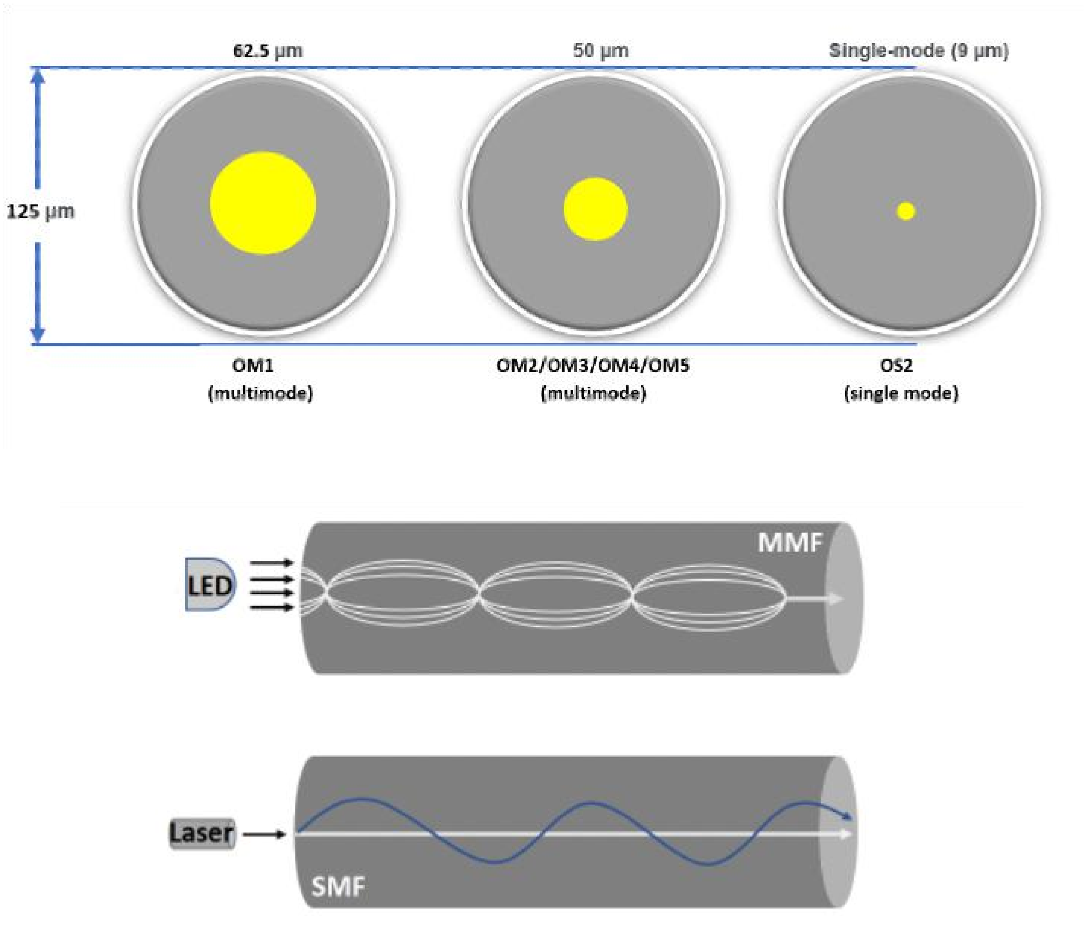

Fig. 3 Comparison between SM and MMF

channel, crossing, and other issues, improve resource utilization rate, reduce the production cost [11]. According to the transmission mode shown in Fig. 1, the IF signal transmission function of the 4K/8K satellite system can also be achieved by fiber.

Generally, optical fiber is classified into single-mode fiber (SMF) and multimode fiber (MMF). In Fig.3, the structure difference between SMF and MMF is shown. SMF uses laser ligh3 Fig Comparison between SM and MMF to which usually follows a single path through the fiber. It consists of a “core” placed at the center, through which electromagnetic signals are guided down to a target location. The core is enclosed inside “cladding”. Cladding utilizes total internal reflection to prevent signal loss or spreading from the core. In commercial optical fibers, two protective layers cover the core and cladding unit. [2] MMF takes multiple paths, which may result in a differential mode delay but can also perform well in short to medium distance communication [8]. The waveguide conditions are different from multimode conditions, optical waveguides need to be specifically designed for each type of mode. Based on the comparison between single-mode and multimode fiber, single-mode fiber optic cabling systems are suitable for large distance data transmission applications and are commonly used in carrier networks, metropolitan networks, and PONs. Multimode fiber optic cabling systems have a smaller radius and are often used in enterprises, data centers and local area networks (LANs). DCF is a combination of SMF and MMF. It can achieve Single-mode and Multi-mode transmission simultaneously. The advantage is that the single-mode light transmitted and combine through the DCF into a spliced multimode fiber can become multimode.

Refer to Fig.4, a more detailed structure of DCF is shown. DCF has a structure with three layers of optical material instead of the usual two. The inner-most layer is

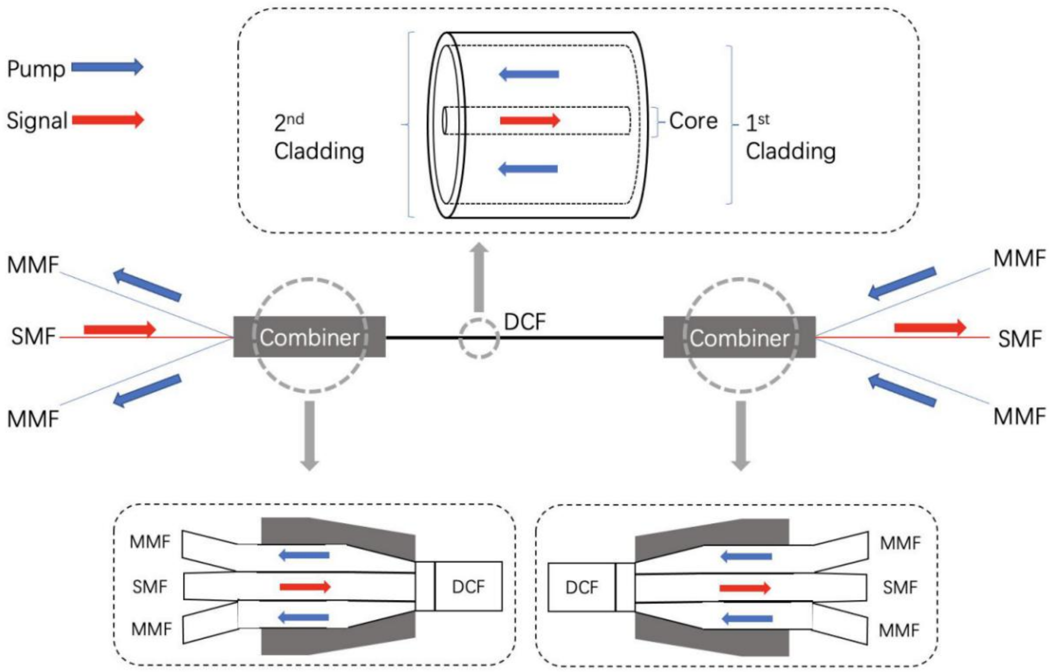

Fig. 4 Schematic of DCF and combiner

called the core. The core is surrounded by the inner cladding. Surrounding outside of the inner cladding is the outer cladding. These three layers are made of materials with different refractive indices. Design of high-power fiber laser and amplifier needs double clad (DC) large mode area (LMA) fiber with larger core and cladding diameter compared to standard SMF to reduce nonlinear effects and damage threshold [9]. By using the combiner, the signal light can be transmitted through the core zone of DCF while the power light can be propagated through the first-clad zone of DCF. Inversely, multimode light in the double-clad fiber will not be transmitted to a spliced single-mode fiber. Double-clad fiber (DCF) is an ideal solution to supply power and transfer signal for the 4k/8k satellite broadcasting.

Especially, DCF technology can transmit energy and signal simultaneously. In the radio and power over fiber system for 4K/8K broadcasting system, the electrical IF signal can be transmitted through an optical fiber with lower attenuation, and the use of PoF technology can supply power to Low Noise Block (LNB) and RoF unit located outdoor. Finally, the combination of signal transfer fiber and power transfer fiber into one double-clad fiber is also considered.

Besides, slices of optical fibers are very thin and fragile. It needs to be put into use in the form of cable in the process of practical application. As shown in Fig. 5, the fiber-optical cable is the type of cable used to carry light by containing one or more optical fibers. They offer significantly higher throughput that copper-based cables, such as coaxial cable or twisted pair cable. The optical fibers may be single mode or multimode. As shown in the figure, it consists of jacket, buffer, and cladding, the chosen optical fiber will have the essential impact on the efficiency of fiber-optical cable. Radio signals are carried over fiber-optic cable, which enables a single antenna can receive all radio signals carried over a single-fiber cable to a central location where equipment then converts the signals. This is opposed to the traditional way

Fig. 5 Breakout Fiber Optical Fiber

where each protocol type requires separate equipment at the location of the antenna.

2.3. BS/CS Broadcasting System in Japan

Digital satellite television broadcasting was started in Japan in 1996 by using communication satellites (CS). These satellite digital broadcasts provide mainly multi-channel standard definition TV services. The broadcasting service with the broadcasting satellite (BS) in Japan started in 2000.

The BS digital broadcasting system can use three different modulation formats, Binary PSK (BPSK), Quadrature PSK (QPSK), and 8PSK. One of them is selected according to transmission and multiplexing configuration control (TMCC) data transmitted with the audio and video data. The CS digital broadcasting system uses only QPSK. Both use similar blocks for PSK demodulation, so it is possible to design a PSK demodulator that demodulates the receipt signals of both BS and CS services.

Although the two standards employ the same technologies in FEC (Forward Error Correction) and audio and video codec blocks, two demodulator components are required to receive both services because there is a difference in the baud rate, and frame format, and modulation scheme. However, since the two demodulators use similar blocks such as phase-locked loop and matched filter, it is possible to implement a new receiver that performs both receptions of BS and CS services. This thesis describes the VLSI architecture of the demodulator for the digital BS/CS broadcasting system.

2.4. Intermediate Frequency

Intermediate Frequency is in the superheterodyne reception, a frequency resulting from combining the incoming signal with a locally produced signal for amplification prior to detection.

Spectrum requirements for the former satellite television broadcasting system is 1032-2071 MHz. To meet the demand for increased pixels and channels, according to Japan's Ministry of Internal Affairs and Communications, the frequency used by 4K/8K TV has been increased to 1032-3224 MHz [3]. However, the cable widely used in the market now has the shortcoming of high system complexity and high signal loss. The increased frequency makes this problem more obvious which causes a serious signal loss when broadcasting.

3. System Configuration

In this section, the configuration of a novel 4K/8K broadcasting system is proposed. Base on the background introduced in the last section, both power and radio needed for 4K/8K broadcasting system can be transferred in the new DCF system. The system also solves the problem of high signal loss with a simple line connection. The high-power light can be transmitted without effect the signal transfer, which makes DCF a good option for combining the power transfer and signal transfer.

The whole configuration of proposed system of 4k/8k satellite broadcasting system is composed as Fig. 6. It consists of 2 parts: E/O and O/E. IF signal is transferred from indoor units to outdoor units represented by the red line path. By

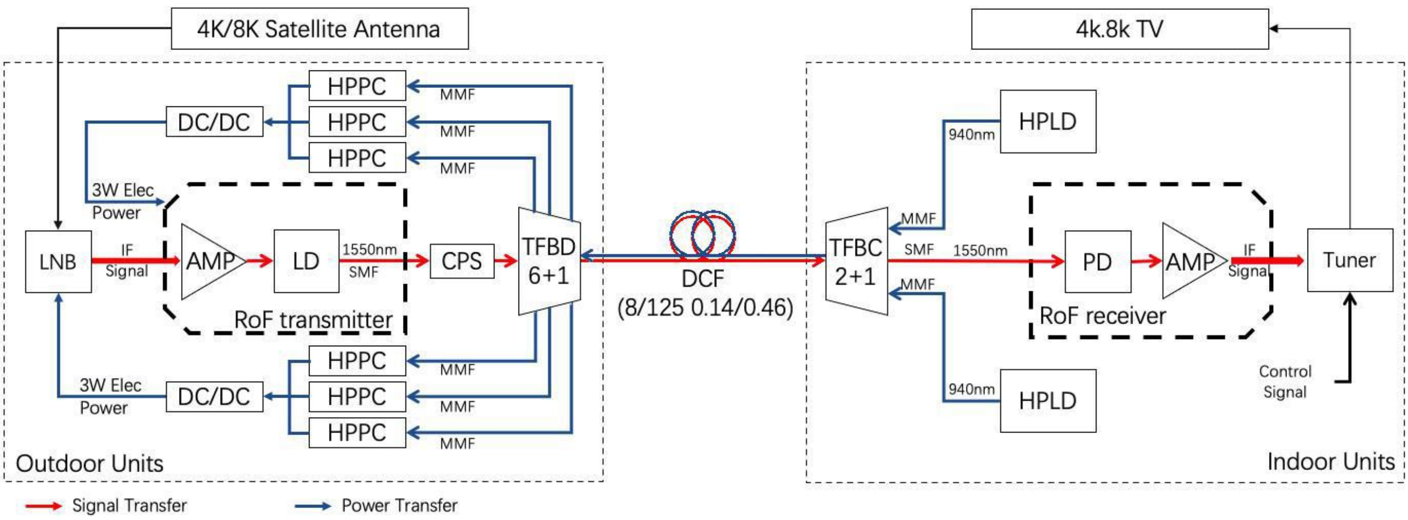

Fig. 6 Configuration of proposed system

using the combiner, the signal laser is transmitted through the core of DCF. The property of DCF can ensure that the single-mode light transmitted through the double-clad fiber into a spliced MMF becomes multimode. Conversely, multimode light in the double-clad fiber will not transmit to a spliced single-mode fiber. The whole process conforms to the principle described in Fig. 1.

In this broadcasting system, a 4K/8K satellite antenna is used to receive the RF signal from the satellite and reflect the RF signal into the Low Noise Block (LNB). The RF signal will be converted into the IF signal in the LNB. The RoF transmitter first amplifies the input IF signal by an amplifier (AMP). Then the amplified signal is used to drive the Laser Diode (LD) under direct modulation. The wavelength of the optical signal generated by the LD is 1550 nm. A 1550 nm wavelength is more commonly used because it has fewer fiber losses, the optical signal in 1310 nm is losing about 0.35 dB/km while the loss is only 0.25 dB/km in 1550 nm [9]. The optical signal is transmitted to the RoF receiver and converted into an electrical IF signal by the Photodiode (PD). After amplifying the converted IF signal, the RoF receiver outputs the IF signal to the tuner where the IF signal will be demodulated into TV images. This is the solution we proposed for solving the high signal loss in

4k/8k satellite broadcasting system by DCF.

The blue line in Fig.3 shows the optical power transfer path. The power laser is propagated through the first-clad zone of DCF from the indoor unit to the outdoor unit. The optical power was generated by using two High-Power Laser Diodes. After the power laser is emitted into two MMFs, the MMFs combined with one SMF into one DCF by the 1×(2+1) Tapered Fiber Bundle Combiner (TFBC). Optical power is transmitted to the outdoor through DCF between two units. While on the outdoor side, a 1×(6+1) Tapered Fiber Bundle Divider (TFBD) is used to divide a DCF into one DCF and six MMFs. The residual power lights are injected into the inner cladding of output DCF, so a Clad Power Stripper (CPS) is needed to strip the power light and allow only signal light to be transmitted through itself. The divided optical power lights are injected into six High-Power Photovoltaic Converters (HPPC) and converted into electrical power. The DC/DC converters are used to elevate the output electrical power to the voltage required by the LNB and RoF transmitter. This system allows the signal transfer and power transfer to be done simultaneously in one DCF.

4. Experimental Setup

4.1. Preparation of experimental equipment

In the experiment, firstly, the power supply of the proposed DCF system is verified. We use PoF technology to supply LNB and RoF units located outdoor. Then we measure the signal transmission ability with PoF supply.

To complete this process, experimental equipment needs to be prepared. Two RoF units are used to do the E/O and O/E conversion to transfer the IF signal through the optical fiber. The 4K/8K satellite antenna is used to receive the RF signal from the satellite and reflect the RF signal into the Low Noise Block (LNB), where the RF signal will be converted into the IF signal. The RoF transmitter first amplifies the input IF signal by an amplifier (AMP) and then uses the amplified signal to drive the Laser Diode (LD) under the direct modulation. The wavelength of the optical signal generated by the LD is 1550 nm. The optical signal is transmitted to the RoF receiver and converted into an electrical IF signal by the Photodiode (PD). After amplifying the converted IF signal, the RoF receiver outputs the IF signal to the tuner where the IF signal will be demodulated into TV images.

4.2. Power Supply in DCF Broadcasting System

Firstly, an experiment of power transfer is conducted. Based on the schematic diagram of Fig. 4, the setup of the PoF process is shown in Fig. 5. From the perspective of transmission efficiency, temperature change of HPLD has a significant influence on output power. On the other hand, to ensure the safety of the experiment, we must also control the temperature. There we set the Laser Control Module and the Temperature Control Module for HPLD. HPLD is set on cooling fan and heat sink. The temperature control module is obtained by setting the temperature sensor on the HPLD. To match the interface, we choose to connect 10m DCF and 1m MMF. Due to the characteristics of fiber, influence of the 1m MMF on the transmission efficiency

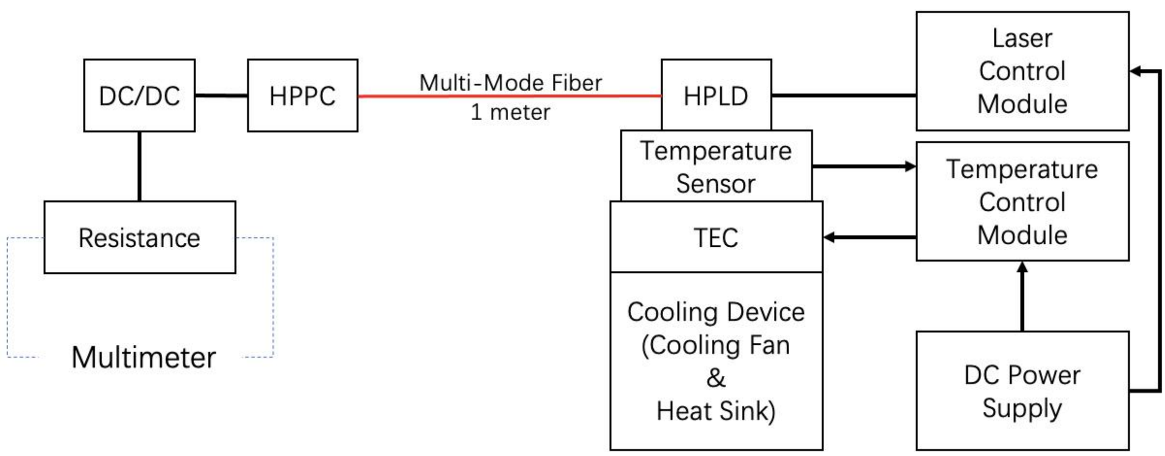

Fig. 7 Setup of experiment on PoF performance

of the whole system can be ignored. At the receiving side, TFBD is used to divide a DCF into 6 power transfer fibers and one signal transfer fiber. Accordingly, the energy transfer is also distributed to the six MMFs. No matter the DCF is divided into how many MMFs, each fiber can only carry 1/10 of the total energy. The residual power lights are injected into the inner cladding of output DCF, so a CPS is needed to strip the power light and allow only signal light to be transmitted through itself. The divided optical power lights are injected into six High-Power Photovoltaic Converters (HPPC) and converted into electrical power. Therefore, the energy transfer of the six MMF terminals needs to be measured separately.

In the experiment, a multimeter is used to measure the voltage and current at the resistance side to calculate the delivered power. The DC/DC converters are used to elevate the output electrical power to a voltage required by the LNB and RoF transmitter. When carrying out the experiment, we give the laser control module and temperature control module a power connection. Fig. 8 shows the setup for energy transmission. The DC power supply supplies energy for the temperature control module and the laser control module. By the software named EasyHost, the output power of HPLD is controlled. It is also used to monitor the real time temperature of

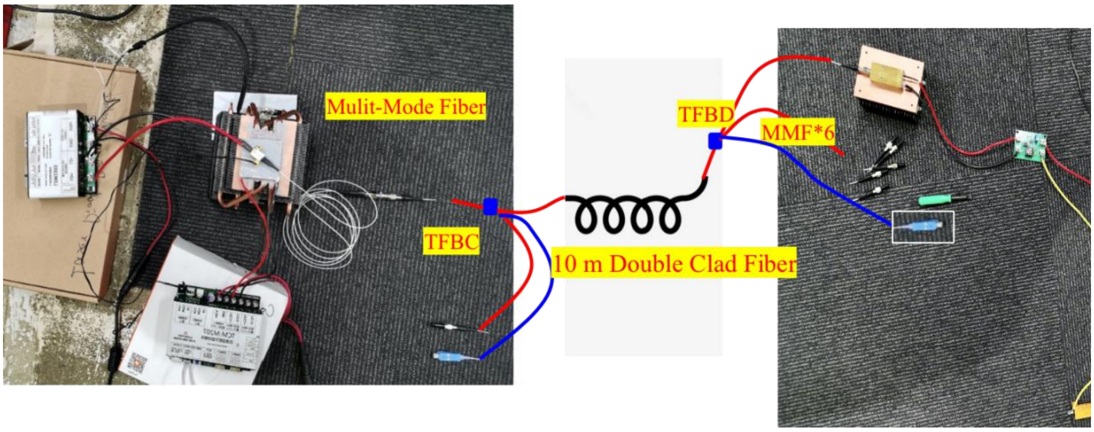

Fig. 8 Actual Setup for PoF transmission

HPLD throughout the experiment. In the outdoor area, a multimeter is used to both measure the voltage across the 12Ω resistor and the current through it. Voltage and current are measured and recorded every ten minutes. By recording and calculating these data, the output power of the 4K/8K broadcasting system using DCF power transmission is obtained.

4.3. Signal Transfer in DCF Broadcasting System

The experimental setup of the 4K/8K broadcasting system with RoF transmission system as the path of IF signal transmission is shown in the Fig. 6. There are two RoF units for the E/O and O/E conversion to make sure the IF signal able to be transmitted through the optical fiber. To receive the RF signal from the satellite and adjusted the antenna to a direction with a maximum received signal level, a commercially available 4K/8K BS/110° CS antenna is prepared [10]. In order the antenna can receive the signal with high level, it is adjusted to the best direction both in horizontal and vertical direction. According to the manual, the best direction can receive the signal with high level is vertical angle around 38 degrees for Tokyo area and rotated the antenna to 231 degrees southwest. The antenna reflects the RF signal into the LNB where the RF signal is converted into the IF signal. LNB is included in the receiver (LNBF) attached to the edge of the parabolic antenna for satellite broadcasting. Generally, the LNB is connected to TV through a coaxial cable directly. Power is supplied to LNB from the TV while the signal transmitted from LNB to TV. In the system we propose, RoF units also achieve the power transfer. There is no need for a separated cable to supply power to the LNB. The RoF transmitter first amplifies the input RF signal by an AMP and then the amplified signal drives the Laser Diode (LD) under the direct modulation. While allowing a maximum 3224 MHz signal transmitted through, the wavelength of the optical signal generated by the LD is 1550 nm. Compared to the figure of the IF extension and the signal distribution of 4K/8K channels, each curve in 2224-3224 MHz can be matched with certain TV channels. It means these curves can be considered as effective signal that contains some TV channels.

4.4. Radio and Power over DCF

When testing the signal transfer ability of the DCF system, firstly the signal transmission ability of DCF is tested when using cable power. The purpose of this initiative is to control for variables. Then test the signal transmission ability when using DCF for power. Comparing the signal spectrum of this control experiment with the signal transmitted through the system which adopts RoF technology, it can be observed that the performance of DCF technology will improve the signal loss performance. The detector of the Spectrum is under "+peak mode, and the trace function is "Normal". The spectrum analyzer's center frequency is set to be 2.15 GHz, which is the dividing line between the old and new IF ranges, and the start frequency is 900 MHz while the stop frequency is 3.4 GHz. This range covers all the broadcasting channels including the new 4K/8K channels so that we can observe the whole signal loss performance.

5. Result and Discussion

Firstly, the energy supply capacity of the system is discussed. According to the data measured by the multimeter, when the HPLD provides 14W input energy, the output power measured at DC/DC side can be stable above 3W. Considering about the actual demand for antenna is 3W, the PoF system proposed gives a sufficient continuous transmission of power over long period of time. Theoretically, because each MMF from TFBD can transmit 10% of the total energy, HPPC conversion efficiency is 30%, and DC/DC efficiency is 90%. The theoretical energy transfer efficiency is 16.2%. To test the equipment feasibility, only 1 HPLD is connected and

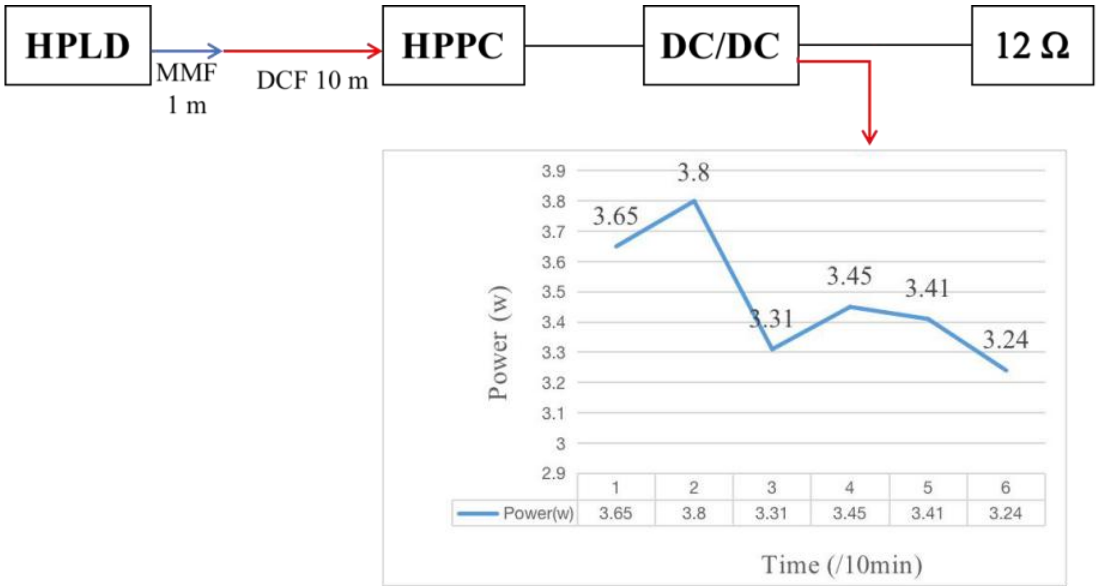

Fig. 11 Output of energy transmission

gives an optical power input of 6W. In this circumstance, power value at the resistance side stays relatively stable at around 1.6W for a long time. It proves that the transmission efficiency meets the expectation and the system is reliable for long-time electrical power support. Based on the above conditions, because the energy requirement for signal transfer is 3W, we set the total input of 2 HPLDs to 14W. To ensure the equipment can still safely supply energy stably when the input power is increased, it is critical whether the output of the PoF system is stable over a long period of time and whether HPLD can keep an appropriate temperature.

In the experiment, as can be seen in Fig. 11, the average value of output power in 1 hour time is 3.48W. The improvement of setting power does not affect the efficiency of energy transmission, and the temperature of HPLD can also keep stable around 40℃. The experimental results are shown in the Fig. 10 and accord with the theoretical inference. Higher the IF frequency, the more significant in signal loss improvement. Frequency area over 2.15 GHz is called high frequency area and frequency area below 2.15GHz is called low frequency area. In Fig. 12, The gray line represents the cable called S5CFB shows that for each effective signal when frequency over 2.15 GHz, especially in 2749-3224 MHz, its amplitude is very low.

The signal transmitted through SMF and DCF are compared and shown in Fig. 12, The red line represents for DCF without PoF, and the green line represents for SMF. Compared with cable, the two lines of optical fiber have better amplitude substantially especially in the high frequency area that they keep the stability. When the HPLD is added in, the proposed system is completed, power of the whole system is supplied by the laser from HPLD. We measure its signal transmission capability, and the performance was shown in Fig. 13. Blue line means signal amplitude of the DCF 4k/8k satellite broadcasting system when PoF is on, and red line means it when PoF is off. Whether HPLDs supply power has not much influence on signal transmission. In low-frequency area, there even has a better performance when PoF is on than when PoF is off. According to our previous research, the average signal loss of SMF is

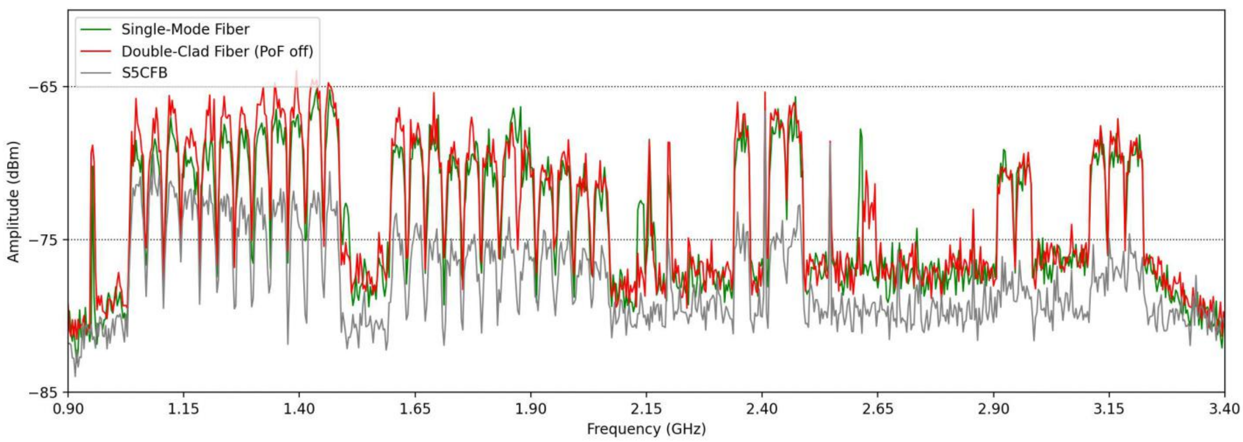

Fig. 12 Comparison between the signals transmitted through Double-Clad Fiber with/without power laser

5.56dB better than S5CFB cable. Fig. 13 shows the signal transmission through DCF when PoF is off and on. The signal transmission of DCF and SMF has similar characteristics[3].

According to the signal distribution shown in Fig. 12 and Fig. 13, we calculated the average amplitude of each effective signal in four frequency ranges separately and filled in Table 1. The average signal loss of DCF without PoF in the whole range 1032-3224 MHz is 0.76dB bigger than SMF. However, the average signal loss of DCF system when PoF on is 0.72 dBm, which is smaller than without PoF. We

Table1

Comparison between the signals transmitted through SMF and DCF with/without power laser

Transmission Method	Frequency Range (MHz)				Average Signal Loss (dB)
	1032-1489	1595-2017	2224-2680	2749-3224	
SMF (S5CFB)	-69.96 dBm	-71.57 dBm	-69.43 dBm	-70.46 dBm	(Used as relative value)
DCF (PoF off)	-68.58 dBm	-70.98 dBm	-68.53 dBm	-70.27 dBm	+0.76
DCF (PoF on)	-68.7 dBm	-70.71 dBm	-68.47 dBm	-70.32 dBm	+0.72

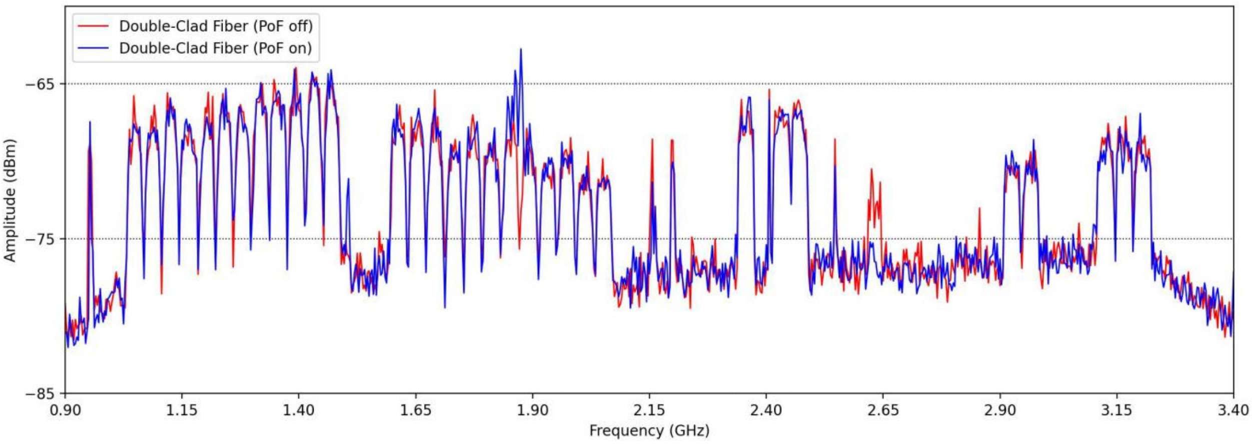

Fig. 13 Comparison between the signals transmitted through Single-Mode Fiber and Double-Clad Fiber

assume that this is because there are two amplitude amplifiers in RoF transmitter of outdoor unit and RoF receiver of indoor unit. Which leads the signal be amplified when transmitted through the two amplifiers.

6. Conclusion

To solve the problem of high signal loss in 4K/8K UHDTV satellite broadcasting system, and to supply power for signal transfer simultaneously, a system using RoF and PoF is discussed. The improvement is made by using DCF with its special structure. The signal transfer fiber and power transfer fiber are combined into one DCF by using the TFBC and TFBD. Firstly, signal transfers in the core of DCF. The experiment result shows that in the required frequency range, like SMFs, the proposed system using DCF gives a better signal loss performance than the system using a coaxial cable. Compared the data we measured between 4K/8K satellite broadcasting system with DCF and it with coaxial cable, an average improvement of 6.32dB is achieved when DCF without PoF, and 6.28dB when DCF with PoF on. The amplitude improvement of signal loss is more significant at high frequency area than at low frequency area. Also, to supply for signal transfer, optical power emitted by HPLD is transmitted through the 1st layer of DCF to the outdoor side. When the total input power by 2 HPLD is 14W, there has a stable output power of 3.48W which is sufficient to supply for signal transfer. This system is with simplicity and well signal loss performance. The breakthrough we make is using HPLD for energy supply to combine RoF and PoF together. In our future work, if the construction process and interconnection technology can be solved, the combination of DCF temperature sensor and DCF broadcasting system is a promising application direction.

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8. Research Achievement

Z. Guo, J. Liu and S. Shimamoto, "Radio and Power over Double Clad Fiber System for 4K/8K Satellite Broadcasting," 2022 IEEE 19th Annual Consumer Communications & Networking Conference (CCNC), 2022, pp. 507-508, doi: 10.1109/CCNC49033.2022.9700525.