Radio and Power over Fiber System for 4K/8K Satellite Antenna

A Thesis Submitted to the Department of Computer Science and Communications
Engineering, the Graduate School of Fundamental Science and Engineering of
Waseda University in Partial Fulfillment of the Requirements for the Degree of
Master of Engineering

Submission Date:01/25/2021

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Research guidance: Research on Wireless Network System

Acknowledgements

I would like to thank my advisor, Prof. Shigeru Shimamoto, firstly for the two years of guidance, support, encouragement, and patient. It is my great honor to have him as my advisor and have the opportunity to study and spend my two years in Shimamoto Lab. Prof. Shimamoto showed me the research direction and always gave me important suggestions on my research problems with the patient. When I found difficulties with my research, he always showed me the way to solve these problems.

And I would like to thank my group leader A.P. Jiang Liu. She gave me a lot of suggestions and inspired me whenever I meet with any problem of my research. As for my research experiment, she also provided me with the most important devices that made my experiment easier to be completed.

I appreciate a lot of the help from the Lab member Yuyu Ying. Without his help, I could not start my experiment successfully. Although we are not in the same group, we often discussed my research a lot, and he gave me lots of encouragement.

Finally, thanks to my parents, who supported me and gave me the chance to study at Waseda University for my master's program.

Abstract

In the new 4K/8K satellite broadcasting, the maximum intermediate frequency (IF) is proposed to be changed from 2071 MHz to 3224 MHz. The coaxial cable has been widely used for IF signal transmission, but the attenuation is significant with a high signal loss when a high-frequency signal is transmitted. With the increasing number of 4K/8K channels and the development of broadcasting technology, the frequency used for the IF signal will keep increasing. Therefore, the coaxial cable may not meet the future ultra-high-definition satellite broadcasting requirements anymore. Compared to the all-electrical signal transmission, the Radio-over-Fiber (RoF) system can achieve signal transmission with lower loss and reduce noise sensitivity by transmitting the signal through an optical fiber.

In this work, we propose a system that uses the RoF technology to reduce the signal loss during high-frequency transmission while adopting the Power-over-Fiber (PoF) technology to generate electric power for Low-Noise Block (LNB) and RoF unit on the antenna side. A method that combines the RoF technology and PoF technology into one Double-clad Fiber is also reported. With the comparison between the signal transmitted through an RoF system and that through a coaxial cable, it can be clearly shown that the advantage of the RoF technology in the signal loss performance. The experimental results of signal transfer demonstrate that by using the RoF technology, the average amplitude of the effective signal containing TV channels increases by 8.89 dB in the range of 2224-3224 MHz, while the average amplitude increases by 5.7 dB for the effective signal in the range of 1032-2071 MHz.

The comparison between coaxial cables and RoF technology shows that changing the

size and material of coaxial cable can not solve the problem of serious attenuation of the high-frequency signal. The system using the RoF technology showed better performance, especially as the frequency increased.

The high-frequency signal transmission experiment demonstrated that comparing with the coaxial cable, RoF technology shows a great advantage in attenuation to ensure that the signal loss will not worsen when the maximum IF is increased higher than 3224 MHz in the future.

The experiment's result on the comparison between optical and electrical signal splitter demonstrated that, in every different frequency range, 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.

Finally, the experiment results on power transfer indicated that the PoF system could be used for a long time and generate a stable electrical power output to supply LNB and RoF transmitter's power consumption.

Keywords: Radio-over-Fiber, Power-over-Fiber, new 4K/8K Satellite Broadcasting, Intermediate Frequency, coaxial cable

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Chapter 1

Introduction

1.1 Background

Satellite Television is a broadcasting service that viewers receive the television programming signal relayed by artificial satellites. The schematic of a general satellite broadcasting system is shown in Fig. 1. The frequency of the signal received from the Broadcasting Satellite (BS) or Communication Satellite (CS) via an outdoor parabolic antenna is around 12 GHz in Ku band. A signal in this high frequency is difficult to be transmitted and processed. So, this Radio Frequency (RF) signal needs to be converted into a signal with a lower frequency called Intermediate Frequency (IF), then it can be transmitted through a coaxial cable to the Set-top Box (STB) with lower signal loss. Finally, the transmitted IF signal is decoded by the STB and output to the TV terminal for viewing.

Fig. 1 The schematic of the general satellite broadcasting system

The range of the IF used in the former satellite broadcasting system is 1032-2071 MHz, and from the Fig. 2, it is clear that the attenuation of all the coaxial cables are not very large in this range. Meanwhile, the effects of external radio waves and noise can be minimized by using the coaxial cable. So, the IF signal can be delivered efficiently with high quality. These

characteristics made the coaxial cable is widely used as an IF signal transmission path in the former broadcasting system. 3C coaxial cable is used around equipment such as TVs and recorders and is used for a short connection. 4C and 5C cables are mainly used at home, 4C is used for indoor wiring, and 5C is used for outdoor wiring.

Fig. 2 Attenuation performance of the coaxial cable

Recently, Japan started the new 4K/8K satellite broadcasting, also called UHDTV broadcasting, on December 1st, 2018, using the BS and 110° CS[1]. The new 4K/8K satellite broadcasting aims to let users experience ultra-realistic viewing which has ultra-high-definition (UHD) video that contains 16 times the number of pixels of high-definition television (HDTV), HDR technology, dramatically increased color gamut and 22.2-channel three-dimensional

sound[2].

According to Japan's Ministry of Internal Affairs and Communications, the new IF range used in the new 4K/8K broadcasting system is 1032-3224 MHz. The extension of the IF and the signal distribution of 4K/8K channels are shown in Fig.3 The maximum intermediate frequency (IF) is changed from 2071 MHz to 3224 MHz[3].

Fig. 3 The extension of the IF and the signal distribution of 4K/8K channels

To be able to watch 4K/8K channels, not only a 4K/8K capable television but also a dedicated satellite antenna to receive the 4K/8K signals is needed. Meanwhile, it said that viewers also need to replace the signal receiving and transmitting equipment such as boosters or distributors that support high-frequency signals transmission. Based on these situations, watching 4K/8K channels will require considerable investment by the consumers.

1.2 Motivation

Although many receiving and transmitting devices have met 4K/8K broadcasting requirements, the coaxial cable as a transmission medium has not made significant progress in technology. Fig. 2 shows that the coaxial cable's attenuation increases rapidly after 2 GHz, so there are more signal losses at high-frequency channels when we transmit the new IF signal through the coaxial cable. Because of the high signal loss along the transmission path between the antenna and the TV, the signal became too weak to be detected by the tuner. Some users reported that they could not watch some 4K/8K channels normally.

It makes the user experience has not been as good as expected despite advances in television and satellite technology that have already satisfied the 4K/8K broadcasting requirements. It becomes a bottleneck of the new 4K/8K satellite broadcasting system. With the increasing number of 4K/8K channels and the development of broadcasting technology, the frequency used for the IF signal will keep increasing. So, a transmission system with low signal loss is needed.

Meanwhile, the LNB is generally connected with TV through a coaxial cable directly that allows supplying the power to LNB from the TV while transmitting the signal from LNB to TV. So, we need to find a new transmission method that can achieve both the signal transfer and power transfer.

1.3 Related Works

Previous 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 a 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 signal over a fiber system[4].

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 use of electrical supply lines outdoors may result in electrical safety and convenience problems. So, one approach to solve this problem involves the use of Power-over-Fiber (PoF) technology.

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 can achieve powering 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 Fiber enables optical fiber to deliver more than 26 W of optical power with a power transmission efficiency of 44.5%[8].

Chapter 2

Radio and Power-over-Fiber System

2.1 Radio-over-Fiber System

Radio-over-Fiber (RoF) technology is a technique common in eliminating the signal loss and increasing the range of communications. Shown in Fig. 4, a schematic of a general RoF system consists of an electric-to-optical (E/O) conversion device where the light is modulated by the RF signal and an optical-to-electric(O/E) conversion device where the radio signal is recovered from the optical signal. These two conversion devices are connected by an optical fiber[9].

Fig. 4 Schematic of RoF system

Compared with the radio signal transmission through the coaxial cable, the optical signal transmitted through an optical fiber has the following advantages[10]:

- 1) The transmission loss is remarkably low.
- 2) The range of the transmission frequency is wide, and the frequency deviation is much small in the optical fiber.
- 3) The RoF system has no remarkable transmission delay because of no signal encoding and decoding.

Therefore, the RoF system can easily achieve tens of kilometer transmission or high-frequency signal transmission with low signal loss.

RoF system has been used for the cable TV (CATV) trunkline system. In the CATV system, an electrical RF signal usually in the range of 54-870 MHz is converted to modulated light at a wavelength of 1310 nm or 1550 nm by optic laser. The light is transmitted through Single-Mode Fiber (SMF) to the optic receiver, converted back to the electrical RF signal, and directly delivered to a TV or set-top box. 1550 nm is more commonly used because it has fewer fiber losses, where the optical signal in 1310 nm is losing about 0.35 dB/km of the while the loss is only 0.25 dB/km in 1550 nm.

There are two kinds of modulation methods, one is the direct modulation. It is commonly used in low-speed, short-distance fiber-optic communication systems with high modulation efficiency. Meanwhile, since the modulator is placed in the cavity, it means increasing the loss in the cavity, reducing the output power. Another modulation method is External Modulation, which is achieved by an external modulator that changes the light characteristics of the laser passing through it. Its modulation efficiency is lower than Direct Modulation[11].

2.2 Power-over-Fiber System

Optical fibers can also be used to transport optical energy to powering electric or electronic devices remotely. This is the concept of Power-over-Fiber (PoF). PoF technology can eliminate the needs for metallic cables or batteries to supply the units located at remote sites, improving the reliability and the security of the system.

A generic PoF system is shown in Fig.5. In the left side, the control unit composed by the high-power optical source (HPOS) unit together with the optical reception unit (ORU) is shown, which receives signals from the remote sensor unit. The optical fibers may be standard Single-mode Fibers or Multimode fibers. 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[12].

Fig. 5 General PoF system diagram

2.3 Double-Clad Fiber

There are two basic optical fiber, one is Single-Mode Fiber (SMF) and another one named Multi-Mode Fiber (MMF). SMF has an excellent attenuation performance at signal transfer but is not widely used in power transfer because the maximum transmitted optical power without causing damages in fiber, usually is under 1W. The signal attenuation of MMF is higher than SMF so that it is usually used for short-distance signal transfer and high-power transfer.

There is one kind of optical fiber named Double-Clad Fiber (DCF), the property of DCF can achieve Single-Mode and Multi-Mode transmission simultaneously. 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, like the Fig.6 shows.

Fig. 6 Schematic of DCF and combiner

Meanwhile, the property of DCF can ensure that the single mode light transmitted through

the double-clad fiber into a spliced multimode fiber will become multimode. Conversely, multimode light in the double-clad fiber will not transmit to a spliced single mode fiber. So, the high-power light can not affect the signal light which makes the DCF become a good option for combining the signal transfer and power transfer fibers into one optical fiber.

Chapter 3

Proposal and System Model

3.1 Proposal

Based on the background we introduced in the first two sections, we proposed a novel 4K/8K broadcasting system using an optical fiber as the IF signal transmission path, which has an excellent attenuation performance compared with coaxial cable.

Fig. 7 Proposal

By using the RoF technique, the electrical IF signal can be transmitted through an optical fiber with lower attenuation, and the use of PoF technology can supply power 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.

3.2 System Model

Fig. 8 shows the configuration of our proposed system. The red line means the IF signal transfer path, and the blue line represent the path of the optical power transfer.

Fig. 8 Configuration of proposed system

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.

The High-Power Laser Diodes are used to generate the optical power and emits the power light into two Multi-Mode Fiber (MMF). Two MMFs and one SMF are combined into one DCF

by the $1 \times (2+1)$ Tapered Fiber Bundle Combiner (TFBC), allowing the signal transfer and power transfer to be done simultaneously through itself.

On the outdoor side, because of better dividing efficiency than $1 \times (2+1)$, a $1 \times (6+1)$ 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 a voltage required by the LNB and RoF transmitter.

Chapter 4

Simulation and Experimental Result

In this chapter, firstly, we simulated the performance of a system which combines the signal transfer and power transfer into one fiber. Then an experiment to measure the performance of PoF system is conducted to see the power conversion efficiency. Next, an experiment on IF signal loss performance of a broadcasting system that adopts RoF technology is conducted, using some coaxial cables as contrast. Meanwhile, an experiment to demonstrate RoF has a great advantage in high-frequency signal transmission for future broadcasting system is also conducted.

4.1 Simulation on Radio-over-Fiber system performance

Before the physical experiment, we used a simulation software named OptiSystem to do a simulation to see the performance of a system which combines the signal transfer and power transfer into one fiber. The simulation module we built based on the system we proposed in Chapter 3 is shown in Fig.9. We used a Dual Port Optical Spectrum Analyzer and a Dual Port RF Spectrum Analyzer to compare the signals before transmitted and after. For the fiber, we chose the Yb Doped Fiber with Double-clad Fiber mode. An optical power meter is used to measure how much optical power has been delivered through fiber.

Fig. 9 Simulation system module

The result RF spectrums and Oscilloscope are shown in Fig.11, It can be seen that compared with the original optical signal generated by the Laser Diode, the optical signal which was transmitted through the proposed module to the PIN Photodiode has the same performance at the wavelength of 1550nm. Meanwhile, the performance of RF signal transfer is as well as the optical signal transfer.

Fig. 10 Optical signals which (a) transmitted to the receiver side and (b) generated by the transmitter

Fig. 11 the RF signal output from the (a) PIN Photodiode and (b) Sine Generator

4.2 Experiment of Power Transfer

Firstly, an experiment of power transfer without the combination of the signal transfer fiber is conducted. Because the change of HPLD temperature can bring the effect to its output optical power, not only the Laser Control Module but also the Temperature Control Module is needed.

The setup of whole PoF system is shown in Fig.12.

Fig. 12 Setup of experiment on PoF performance

We set the output optical power of HPLD at 6W first and used a multimeter to measure the voltage and current at the resistance side so that we can calculate the delivered power. The results are filled in TABLE.1. It can be seen that the optical-to-electric conversion efficiency is around 30.3% while the DC/DC conversion efficiency is about 89%, which are same as the property of HPPC and DC/DC converter.

TABLE. 1 RESULT OF POWER TRANSFER

	HPPC side	Resistance side
Voltage	17.5V	3.7V
Current	104mA	0.437A
Power	1.82W	1.62W
Efficiency	30.3%	89%

Meanwhile, the PoF system in our proposal is used to do a continuous transmission of energy over a long period of time. So, it is also very important that whether the output performance of the POF system is stable over a long period of time. Because our target transferred electrical power is 3W, we set the output optical power of HPLD at 10W this time and measured the power value every 5 minutes over an hour. The result is shown in Fig and it can be seen that the power value is around 3.2W and relatively stable. So, this PoF system can be used for a long-time, and can generate a stable electrical power output.

Fig. 13 Values of electrical power for 1 hour

4.3 Experiment of Signal Transfer

4.3.1 IF Signal Transmission

Fig.14 shows the experimental setup of a 4K/8K broadcasting system using an RoF transmission system as the path of IF signal transmission. Two RoF units are used to do the E/O and O/E conversion to make the IF signal can be transmitted through the optical fiber.

Fig. 14 Experimental setup of the 4K/8K broadcasting system using Radio-over-Fiber transmission

We prepared a commercially available 4K/8K BS/110°CS antenna to receive the Radio Frequency (RF) signal from the satellite and adjusted the antenna to a direction with a maximum received signal level. The antenna reflects the RF signal into the Low Noise Block (LNB) where the RF signal is converted into the IF signal.

Generally, the LNB is connected with TV through a coaxial cable directly that allows supplying the power to LNB from the TV while transmitting the signal from LNB to TV. In this work, we proposed a system with RoF units that cannot achieve the power transfer, so that we also need a power supply that can provide the power to the LNB while allowing a maximum 3224 MHz signal transmitted through itself. The RoF transmitter first amplifies the input RF

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.

Fig. 15 Setup of outdoor units and indoor units

Through a Single-Mode Fiber (SMF), the optical signal is transmitted to the RoF receiver and converted into an electrical RF signal by the Photodiode (PD). After amplifying the converted RF signal, the RoF receiver outputs the IF signal to the USB spectrum analyzer (RSA306B) which is used to observe the 4K/8K signal. The maximum frequency range of RSA306B is 9 kHz to 6.2 GHz, covering all the new IF range. So, this USB spectrum analyzer can meet the requirements of our experiment.

To minimize the signal loss caused by the coaxial cable's attenuation, we use two connectors to connect the RoF units with the power supply and spectrum analyzer directly.

As a comparison, we also used several coaxial cables to do the transmission experiment and used the same spectrum analyzer to observe the signal spectrum, includes:

- 1) S5C-FB(15m): It has the best attenuation performance among the commercially available 4k/8k coaxial cable.

- 2) 5C-2V(15m): widely used in the former satellite broadcasting system (UHF/VHF).
- 3) S4C-FB 2k4k8k (15m): It is included in the 4K8K antenna set.
- 4) S2.5C-FB (15m): It supports terrestrial digital broadcasting/ BS / CS digital.

The setup is shown in Fig. 16:

Fig. 16 Setup of the control experiment.

Comparing the signal spectrums of this control experiment with the signal transmitted through the system which adopts RoF technology, we can observe how much the RoF technology will improve the signal loss performance.

According to the extension of the IF and the signal distribution of 4K/8K channels figure shown in first section. We set the spectrum analyzer's center frequency at 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 includes the new 4K/8K channels, so that we can observe the whole signal loss performance. The detector of the Spectrum is under “+peak mode”, and the trace function is “Normal”.

Fig.17 shows the resulting spectrum of the signal transmitted through RoF system (green line) and the signal wave transmitted through S5C-FB (blue line) and 5C-2V (red line). Compared with the figure of the extension of the IF and the signal distribution of 4K/8K

channels, each curve in 2224-3224 MHz can be matched with some TV channels, which means these curves can be considered the effective signal that contains some TV channels.

Fig. 17 Spectrum of IF signal transmitted through RoF (green line), S5C-FB (blue line), and 5C-2V (red line)

The blue and red line show that the signal loss in the high-frequency area (higher than 2.15 GHz) is more than the low-frequency area (lower than 2.15 GHz). Meanwhile, for each effective signal in a high-frequency area, the amplitude is very low, especially in 2749-3224 MHz. However, the whole green line's amplitude is substantially better, especially in the high-frequency area. Compared with the low-frequency area, the amplitude of the high-frequency area does not decrease significantly but keeps the same value as that of the low-frequency area.

To see more clearly how much the amplitude increases with the increase in frequency using the ROF, we set the detector of spectrum as “+peak, Avg (VRMS)”, used the amplitude of each coaxial cable as the relative value, calculated the improved amplitude value in each frequency.

The results are shown in Fig.18.

Fig. 18 The spectrum of the improvement (under +peak, Avg(VRMS))

From the Fig.18, it is clear that the higher the IF range, the more significant the improvement. Compared with the 5C-2V, an improvement higher than 12.5 dB is achieved by using RoF system while a 10 dB improvement is achieved by using RoF instead of S5CFB.

According to the signal distribution shown in Fig. 3, we calculated the average amplitude of each effective signal in four frequency ranges separately and filled the results in TABLE.2. The RoF system's signal loss performance is better than all coaxial cables, especially in 2749-3224 MHz. Compared with the S5CFB, an average improvement of 9.89 dB is achieved by using RoF. The performance of signal loss is improved more significantly at high frequencies than at low frequencies.

TABLE. 2 AVERAGE AMPLITUDE RESULTS

Frequency Range (MHz)		Average amplitude of the effective signal (dBm)			
		Improved amplitude (dB) (compared with each coaxial cable)			
		RoF	S5CFB	5V2C	S4CFB
Old IF range	1032-1489	-51.61	-55.64 4.03	-57.07 5.45	-55.98 4.37
	1595-2017	-52.99	-59.31 6.32	-61.65 8.67	-60.45 7.46
New extended IF range	2224-2680	-49.78	-57.67 7.89	-59.55 9.78	-58.16 8.38
	2749-3224	-51.33	-61.21 9.89	-63.18 11.85	-61.33 10.00

Compared with the S5CFB, the average amplitude of the effective signal, which is transmitted through RoF system, increases by 8.89 dB in the range of 2224-3224 MHz, while the average amplitude increases by 5.18 dB for the effective signal in the range of 1032-2071 MHz.

4.3.2 Comparison Between Coaxial Cables

Several groups of contrast are also conducted, includes S5CFB-RoF, S2.5CFB-S5CFB and 5C2V-S5CFB, to see how much the signal loss performance can be improved by changing the material or diameter of coaxial cable. And whether this improvement is more significant than the improvement provided by using the ROF technique.

Fig. 19 Improved amplitude between RoF and S5CFB (red line), S5CFB and S2.5CFB (green line), S5CFB and 5C2V (blue line)

As can be seen from the Fig.19, the improvement brought by using different coaxial cables remains the same, which means that the problem of high frequency signal attenuation has not been solved. However, the increase brought by the use of ROF increases with the increase of frequency, which effectively solves the problem of excessive attenuation of high-frequency signals.

We calculated the exact average improvements of these three groups and filled the number in TABLE.3. The improvement between S5CFB and S2.5CFB is significant, but it still slighter than the improvement between S5CFB and RoF. It shows that increasing the diameter of coaxial cable is not the best solution for signal loss in high-frequency transmission. Meanwhile, the improvement between S5CFB and 5C2V is small which means that changing the material of

coaxial cable is not a solution either.

TABLE. 3 AVERAGE IMPROVEMENT

	Avg improvement (dB)
S5CFB → RoF (1032~2071 MHz)	5.18
S5CFB → RoF (2224~3224 MHz)	8.89
S2.5CFB → S5CFB	5.16
5C2V → S5CFB	2.34

Through the comparison of these groups, it can be seen that changing the size and material of coaxial cable can not solve the problem of serious attenuation of high frequency signal. The system using the RoF technology showed better performance, especially as the frequency increased.

4.3.3 High-Frequency Signal Transmission

As mentioned in Motivation Section, with the increasing number of 4K/8K channels and the development of broadcasting technology, the frequency used for the IF signal will keep increasing in the future. So, we need show our proposed method has a better signal loss performance in not only this new 4K/8K broadcasting system but also the broadcasting system which has a much higher IF in the future.

An experiment of high frequency signal transmission was conducted, used a signal generator as the signal source to generate signals at 3/4/5/6 GHz separately, and used four kinds of coaxial cables to transmit these signals. Due to the limitation of our RoF units, which can only transmit the signal under 3 GHz, we used the simulation software to simulate the RoF performance at 3/4/5/6 GHz and set the amplitude of virtual signal generator output as the same as the real signal generator, which is 5 dBm. The setup of experiment is shown in Fig while the simulation module is shown in Fig.20.

Experiment:

Fig. 20 Setup of high frequencies transmission

Fig. 21 Simulation system module

Fig.20 shows the spectrum of the signals transmitted through S5CFB while Fig.21 shows the simulation results in each frequency, and the observed amplitudes are filled in table. Comparing the values of RoF (simulation) and S5CFB at 3 GHz in TABLE.4, it can be seen that the improvement at 3 GHz is around 11.53 dB which is almost as same as the result we got in the former IF signal transmission experiment. It demonstrated that our simulation data is reliable and can be compared with the actual experimental data.

Results show that with the increase of frequency, the change of RoF signal loss performance in each frequency is slightly, which is about 0.000002 dB. Compared with the amplitudes of signal transmitted through S5CFB, the RoF technology shows a great advantage in attenuation to ensure that the signal loss will not worsen when the maximum IF is increased higher than 3224 MHz in the future.

TABLE. 4 RESULT OF HIGH FREQUENCY SIGNAL TRANSMISSION

	3GHz	4GHz	5GHz	6GHz
RoF(simulation)	-12.293911 dBm	-12.293913 dBm	-12.292579 dBm	-12.293917 dBm
S5CFB	-23.82 dBm	-27.05 dBm	-33.04 dBm	-33.24 dBm
Improvement	11.526089 dB	14.756087 dB	20.747421 dB	20.946083 dB

Fig. 22 Spectrum of 3/4/5/6 GHz signal transmitted through S5CFB

Fig. 23 Spectrum of simulation results in each frequency

4.3.4 Comparison between optical and electric signal splitter

In the former experiments, it is assumed that there is only one television in the broadcasting system. However, there could be more than one television receiving the signal from one broadcasting antenna in a real usage scenario so that the electrical splitters are needed to split one electrical IF signal into several. After the splitting, an electrical signal booster is usually needed because the IF signal becomes too weak to be detected by the TV tuner. It can be seen that not only the electrical splitter but also the booster is needed to be replaced once the maximum IF is increased to more than 3224 MHz in the future.

There is a kind of fiber optic coupler used to split the optical signals, just like the electrical splitter. To show whether the optical signal splitter has a better signal loss performance than the electrical signal splitter, two groups of control experiments are conducted. The experiment setup is shown in Fig.24, comparing the performance of the 50:50 both optical and electrical signal splitter.

Fig. 24 Setup of experiment on comparison between optical and electrical signal splitter

First, the result of signal loss performance comparison between 50:50 optical and electrical signal splitter is shown in Fig.25.

(a)

(b)

Fig. 25 Comparison between 50:50 (a) electrical and (b) optical signal splitter

It can be observed from Fig.25 (a) that after a 50:50 electrical signal splitter, the amplitude of both two ports is very low and close to the noise value. Even if a booster is used to amplify the output IF signal, the split signal is still very difficult for the TV tuner to distinguish the effective TV channels signal from the noise. However, Fig.25 (b) showed that the split signal almost has the same amplitude with the original signal that transmitted through the coaxial cable, which guaranteed that the effective TV channels signal can be easily detected even without any amplifier.

From the TABLE.5, it demonstrated that the RoF technology with a 50:50 signal splitter has a remark advantage in every different frequency range, compared with the coaxial cable with an electrical 50:50 signal splitter.

TABLE. 5 RESULT OF COMPARISON BETWEEN 50:50 OPTICAL AND ELECTRICAL
SIGNAL SPLITTER

Frequency Range	RoF_original signal	RoF_50:50 _01	RoF_50:50 _02	CC_original signal	CC_50:50 _01	CC_50:50 _02
1032-1489	-49.05	-53.95	-52.18	-53.18	-56.98	-57.46
1595-2017	-50.83	-56.58	-55	-56.42	-59.97	-59.99
2224-2680	-49.5	-54.58	-52.65	-54.72	-59.2	-59.13
2749-3224	-48.99	-57.59	-55.8	-57.41	-60.51	-60.35

Chapter 5 Conclusion and Future Work

5.1 Conclusion

Signal loss performance is essential to the new 4K/8K satellite broadcasting system, affecting the actual user experience. Even the broadcasting technology and the TV have been prepared, the remarkable signal loss on coaxial cable prevents users from enjoying 4K/8K technology.

In this work, we proposed a low signal loss transmission method for the new 4K/8K satellite broadcasting system using an RoF transmission system that has an excellent signal loss performance in high-frequency and long-distance signal transmission. The experiment result shows that the system that adopts RoF as the transmission path clearly gives a better signal loss performance than the system using a coaxial cable in each frequency range. A 9.89 dB improvement of the average amplitude is achieved by using the proposed system to transmit the IF signal at 2749-3224 MHz.

The comparison between coaxial cables and RoF technology shows that changing the size and material of coaxial cable can not solve the serious attenuation of the high-frequency signal. The system using the RoF technology showed better performance, especially as the frequency increased.

The high-frequency signal transmission experiment demonstrated that comparing with the coaxial cable, RoF technology shows a significant advantage in attenuation to ensure that the signal loss will not worsen when the maximum IF is increased higher than 3224 MHz in the

future.

The experiment's result on the comparison between optical and electrical signal splitter demonstrated that, in every different frequency range, 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 be detected without any amplifier.

Furthermore, the experiment results on power transfer indicated that the PoF system can be used for a long time and can generate a stable electrical power output to supply LNB and RoF transmitter's power consumption.

5.2 Future Work

The present work focused on the using RoF technology to improve the signal loss performance of IF signal and applied the PoF technology through another optical fiber to deliver optical power to the outdoor side. In future work, we are planning to use double-clad fiber to combine the signal transfer fiber and power transfer fiber into one optical fiber by using the TFBC and TFBD.

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Research Achievement

- Ziyu GUO, Jiang Liu, Shigeru Shimamoto, “*Radio and Power over Fiber System for 4K/8K Satellite Antenna*”, 2020 IEEE International Conference on Communication, Networks and Satellite (Comnetsat), Dec.17~18, 2020.