

**APT REPORT**

**on**

**RADIO-OVER-FIBER RELAY LINK FOR INDOOR COMMUNICATION SYSTEMS**

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**Table of Contents**

1. **Introduction**
2. **Scope**
3. **References**
4. **Abbreviations and acronyms**
5. **RoF relay link applications at home environment**

**5.1 System architecture**

**5.2 System features**

1. **System demonstration**
2. **Discussion**
3. **Conclusion**
4. **Introduction**

This APT Report summarizes architectures and characteristics of Radio over Fiber (RoF) relay links for indoor communication systems to connect wireless devices which are wirelessly disconnected by obstacles such as concrete walls, floors, etc. RoF relay transmission links can transmit RF signals in the frequency range from microwaves to millimeter-waves due to broadband conversion characteristics of O/E and E/O devices [1]. If RF signals cannot penetrate the walls between two rooms in the house, and optical fiber cables are already installed between two rooms, then the RF signals can be transmitted from one room to the other through an optical fiber cable. RoF relay transmission links cannot be only applied to indoor communication systems, but also to outdoor repeaters to provide subcarrier frequencies for the broadcasting and mobile systems. This APT Report focuses on RoF relay link applications to indoor communication systems and the related RoF technologies.

1. **Scope**

This Report provides the technical guideline of RoF relay links which connect wireless devices located at wirelessly disconnected areas, and their characteristics at millimeter-wave frequencies.

1. **References**

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1. **Abbreviations and acronyms**

EDFA Erbium-Doped Fiber Amplifier

FTTH Fiber To The Home

LD Laser Diode

MZM Mach Zehender Modulator

OBPF Optical Bandpass Filter

PD Photodiode

QPSK Quadrature Phase Shift Keying

RF Radio Frequency

RoF Radio over Fiber

SFDR Spurious-Free Dynamic Range

SNR Signal-to-Noise Ratio

WLAN Wireless Local Area Network

WPAN Wireless Personal Area Network

1. **RoF relay link applications at home environment**

**5.1 System architecture**

The system architecture is shown in Figure 1. The millimeter-wave frequencies, 60 GHz in particular, are utilized for indoor-type short range data communication such as WLAN and WPAN [2][3]. The disadvantages of millimeter-wave frequencies such as 60 GHz are a large attenuation loss due to gaseous, cloud and fog [3][4], as shown in Figure 2. The link budget of 60-GHz indoor systems is calculated using these attenuation characteristics.



Figure 1 System architecture of RoF relay link.



Figure 2 Attenuation characteristics of millimeter-wave frequencies [2].

Another important parameter to design indoor 60-GHz systems are the penetration loss of materials used for houses, as shown in Table 1. The extremely large insertion loss is added by the concrete wall whose penetration loss is greater than 40 dB. However, the penetration loss by plaster wall and glass is much smaller than that of the concrete. The 60-GHz frequency may propagate from one room to another one if these rooms are separated by either plaster walls or glasses. The concrete walls are generally used for in large part of rooms in the apartment buildings. The other transmission media between rooms separated by the concrete walls is required to transmit RF signals from one place to another, and vice versa.

Table 1 Example of penetration loss [6]

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Vertical polarization | Horizontal Polarization | Circular Polarization |
| Concrete Wall | ＞40dB | ＞40dB | ＞40dB |
| Concrete Board | 23.7dB | 25dB | 24.2dB |
| Plaster Wall | 6.5dB | 5dB | 4.6dB |
| Glass | 1.5dB | 1.3dB | 2dB |



Figure 3 In-building RoF relay link for WLAN.

In Japan, the optical fiber cables are already installed in the apartment buildings and houses to provide FTTH services to the customers [7][8]. If O/E and E/O converters are connected to these equipped fiber cables, the millimeter-wave signals can be transmitted from one room to another one, and vice versa, where these rooms are wirelessly disconnected by the concrete walls. The RoF link can extend service areas in the apartment buildings.

**5.2 System features**

* Wireless zones are connected via RoF relay link. The individual wireless zones can support high-speed-data traffic requirements that are limited by the high throughput link capabilities.
* Traffic is bidirectional and is comprised of subcarriers which include data, voice, video, and any kinds of signals. These subcarriers are radio frequencies, such as 60 GHz frequencies. RoF relay link extends coverage areas without any performance degradation and any changes of traffic requirements.
* Environment can be home and apartment. The RoF realy link distance can be extended up to a few meters due to latency of E/O and O/E conversions. Typical areas which are connected via optical fiber cables are electromagnetically isolated. No degradation of system characteristics can be managed by use of RoF relay link.
* RoF relay link can carry any type of traffic due to broadband transmission capability and linear characteristics of E/O and O/E devices. No additional traffic conditions are introduced by RoF relay link.
* Use case
	+ Electromagnetic isolated spaces such as rooms of houses surrounded by concretes are directly connected through RoF relay link without any digital signal processing units of relay stations.
	+ In spite of physical and electromagnetic separation, one wireless zone is extended to another wireless zone through optical fiber cables.
	+ Users at different locations can take advantage of broadband multi-media applications.
1. **System demonstration**

Figure 4 shows a blockdiagram of the 60-GHz signal transmission experiment through an optical fiber cable. The 60-GHz signals received by the 60-GHz receiver modulate the optical carrier from the LD. A polymer-based MZM was used because of its broadband modulation capability. An EDFA increased the optical power to compensate for the insertion loss of the MZM of around 20 dB. An OBPF with an optical bandwidth of 1 nm suppressed the amplified spontaneous emission noise caused by the EDFA to enhance the SNR. A PD with a bandwidth of 70 GHz detects the RF signals and sends it to the 60-GHz Transmitter.

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Figure 4 Blockdiagram of system demonstration.

Figure 5 shows the amplitude frequency response of the RoF relay link shown in Figure 4. These intrinsic responses do not include the characteristics of electrical components. The measured link losses without fiber cable at a frequency of 40 GHz and 60 GHz are about -22 dB and -25dB, respectively. The difference of the link loss at each frequency depends on the amplitude frequency response of MZM optical modulator. The slope of the frequency response can be compensated by tuning the electrical devices such as amplitude equalizers.

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Figure 5 Amplitude frequency response of RoF relay link.

A vector network analyzer is used for evaluation of the link gain and the SFDR. The electrical bandwidth of the network analyzer is 70 GHz. The SFDR is measured by a two-tone method whose separation is 1 GHz at a center frequency of 60 GHz. The RF output power of the fundamental and third-order intermodulation components is proportional to the input RF power and to the cubes of the power, respectively. The observed SFDR is about 80 dBHz2/3, as shown in Figure 6. We note that the noise floor used for evaluation of the SFDR is equivalent of that of the vector network analyzer.

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Figure 6 SFDR characteristics of RoF relay link.

Figure 7 shows EVM characteristics at the 60-GHz transmitter output. The observed EVM of QPSK modulated signal is 3.3 % by an electrical back-to-back configuration and 12.7 % with a fiber cable length. These results show that EVM is degraded by connection of RoF relay link, however there remain some possibilities to improve both SFDR and EVM of RoF relay link by selecting low noise RF amplifiers for PD output and RF driver amplifiers for MZM input. The optimum parameters of these devices will be determined according to system requirements. Figure 8 shows EVM characteristics of 16 QAM modulated signal and its spectrum. 14 % value was obtained. The center frequency of the spectrum is 64.8 GHz and the observed spectrum satisfies with the mask specified with IEEE 802.11 device.



1. RF back to back (b) RoF relay link with an optical fiber cable of 180 m

Figure 7 EVM characteristics of RoF relay link.



Figure 8 EVM characteristics of 16 QAM signal through RoF relay link.

Figure 9 shows the relationship between EVM and fiber cable length of RoF relay link. These results indicate that the EVM characteristics are independent from the fiber cable length but dependent from the center frequencies of each channel and modulation scheme of the transmission signals.



Figure 9 EVM vs. fiber cable length of RoF relay link.

1. **Discussion**

RoF relay transmission link is proposed to transmit RF signals from one place to the other whose places are wirelessly disconnected. Data transmission experiment of RoF relay link is presented and EVM of transmitted signals are less 13 %. Additional delay time caused by RoF relay link is about 350 ns at a fiber cable length of 50 m. Spurious free dynamic range of RoF relay link is improved up to 80 dBHz3/2. Table 1 summarizes one examples of RoF-relay-link specification.

Table 1 Example of specification of RoF relay link.

|  |  |
| --- | --- |
| Bandwidth | 60 GHz +/- 1GHz |
| Gain (at optical input power of +8 dBm) | -7 to 8 dB (depends on config.) |
| Noise figure (at optical input power of +8 dBm) | ~8 dB |
| Latency | <100 ns |
| Optical wavelength | 1550 nm |
| Receivable input power at O/E | -20 dBm min. /+8 dBm max.(changes Gain and NF) |
| SFDR (at optical input power of +8 dBm) | 84 to 70 dBHz2/3 (depends on config.) |

1. **Conclusion**

Fiber cables installed in the house or apartment can be used as one of infrastructures to transmit analog radio signals from one place to the other which is electromagnetically isolated and vice versa, if adequate E/O and O/E devices with antennas are connected to optical fiber cables. The current study indicates that high-speed data transmission over 22 Gbps is feasible using broadband MZM optical modulator and high-sensitivity photodiode via 31-GHz carrier frequency [9]. The RoF relay link can be expected not only as indoor applications but also outdoor ones such as mobile radio relay stations.