Millimeter-wave Impulse Radio Technology

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With a drastic increase in the amount of network traffic in recent years, there is now greater demand for large-capacity transmission even in multi-radio systems which are infrastructure for communication transmission lines. However, with conventional multi-radio systems it is difficult to ensure a wide frequency band and in addition equipment is required for multi-radio channels owing to the limitations of modem technology, and this means that systems consist of large equipment and there is a big problem in terms of handling and economy before multi-radio systems can be put to practical use. Hence, Fujitsu used the millimeter-waveband where it is possible to ensure a wide bandwidth, and in particular the E-band (70–80 GHz band), which is less susceptible to attenuation caused by the atmosphere. We utilized impulse radio technology that successfully achieved 10 Gb/s radio communication in a proof of principle experiment, and developed a very compact (4L, 4.5 kg) large-capacity piece of transmission equipment (maximum transfer rate: 3.6 Gb/s). This paper introduces the features and key technology of E-band impulse radio equipment, and the configuration and characteristics of the equipment we developed. It also gives some application examples.

1. Introduction

Communication network traffic is showing explosive growth as mobile devices become widespread and the amount of information in content increases. Even in the conventional microwave radio system, which is infrastructure for communication transmission lines, there is now a demand for larger-capacity transmission as with optical communication.

However, to increase radio transmission capacity, the wider frequency band and a large scale of multiple-radio channels using the conventional modem technology are required and from practical and economical operation points of view, a technical breakthrough is necessary.

To address this issue, we at Fujitsu focused on millimeter-wave band that can ensure a wider frequency band, especially the E-band (70–80 GHz band) which is less susceptible to atmospheric attenuation. As the modulation scheme, we newly developed our proprietary impulse radio technology, totally different from the conventional modulation such as n state-QAM that modulates the amplitude and phase of a carrier wave according to information. This element technology was developed in contract research with the Ministry of Internal Affairs and Communications of Japan and we verified the capability of 10 Gb/s radio communication in a principle experiment.[1)–3)] Based on these results, we have realized a very compact (4L, 4.5 kg) large-capacity piece of transmission equipment (maximum transfer rate: 3.6 Gb/s) in line with laws relating to telecommunications.[4)] This has made it possible to employ radio communication even in an environment where that was extremely difficult with the conventional radio system due to the lack of transmission capacity.

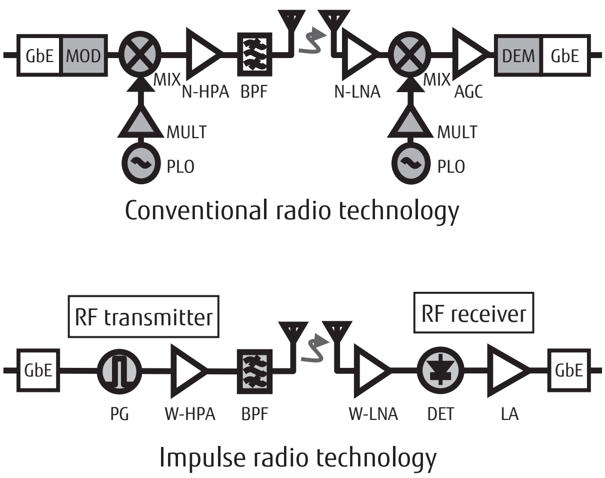
This paper presents the features of the E-band impulse radio we developed, key technologies including the principle, configuration and specifications of the equipment, an evaluation of the characteristics including the result of a field experiment, and application examples.

2. E-band impulse radio technology

2.1 Features

As millimeter-wave bands have high frequencies they allow a wide band to be used. So, they are suited for large-capacity transmission. The E-band, in particular, is called an "atmospheric window" and has low attenuation caused by H_2O and O_2,[5] which makes it suitable for radio communication. In addition, the high frequencies provide high rectilinearity and resistance to interference from other systems, which allows large-capacity transmission (3.6 Gb/s) in both upstream and downstream directions by duplex operation (71 to 76 GHz and 81 to 86 GHz). Furthermore, the high antenna directivity makes it possible to realize a star topology with a small separation angle by using the same frequency.

Figure 1 shows the difference between the conventional radio technology that uses an up-and-down converter and impulse radio technology. The impulse radio technology eliminates the need for an up-and-down converter composed of a modulator (MOD), demodulator (DEM), oscillator (PLO), multiplier (MULT) and mixer (MIX), which is used in the conventional radio technology, and allows for a simple configuration, facilitating size reduction, low power consumption and low delay. It can be combined with natural energy thanks to the low power consumption and is useful as a green product that is environmentally friendly. Its compact and lightweight features make it possible to easily build temporary links for purposes such as broadcasting of events and network restoration.



AGC: Automatic gain controller
BPF: Band-pass filter
DEM: Demodulator
DET: Envelope detector
LA: Limiter amplifier
MIX: Mixer
MOD: Modulator
MULT: Multiplier
N-HPA: Narrow-band, high-power amplifier
N-LNA: Narrow-band, low-noise amplifier
PG: Pulse generator
PLO: Phase lock oscillator
W-HPA: Wide-band, high-power amplifier
W-LNA: Wide-band, low-noise amplifier

Figure 1
Difference between conventional radio technology and impulse radio technology.

2.2 Key technologies

The following describes the key technologies used in the transmitter and receiver that realize impulse radio at a high frequency of the E-band.

1) Technology to generate transmission impulses

Impulse signals responding to the input signals are generated by using the ultra-short pulse generation technology that applies elemental technologies developed by Fujitsu Laboratories. We have developed a technology that filters the impulse signals and extracts the E-band spectrum to transmit wave packets.

2) Received signal detection technology

We have developed a technology for detecting envelopes of wide-band impulse signals from wave packets with low distortion and low noise by making use of analog circuit technology.

3) Wide-band amplification technology

In order to obtain the input signals required for transmission power amplification and detection in transmission and reception, we have developed a wide-band amplification technology featuring flat frequency characteristics over a wide band.

4) Filter technology

We have developed a filter technology for extracting with low distortion E-band wave packets from components spread over the frequency domain by impulse generation and for eliminating spurious emissions.

Figure 2 shows the principle of impulse radio technology from impulse generation to envelope detection.

3. E-band impulse radio equipment

3.1 Configuration

We have made use of the technologies described above to develop a piece of E-band impulse radio equipment. The equipment is composed of blocks 1) to 5) listed below (**Figure 3**).

1) Baseband (BB) block

Composed of a user interface physical layer PHY, forward error correction (FEC), radio frame generation and monitoring/control functions.

2) Millimeter wave transmission block

Composed of an impulse generator, BPF, radio frequency amplifier (RF AMP) and high power frequency amplifier (HP RFAMP).

3) Millimeter wave reception block

Composed of an LNA, RF AMP and envelope detector.

4) Diplexer

5) Power supply block

Table 1 shows the major specifications of the impulse radio equipment.

As the user interface, Ethernet (10GbE or GbE) and common public radio interface (CPRI) are supported. The Ethernet (10GbE or GbE) interface is equipped with an L2 switch function and supports a virtual LAN (VLAN) function.

For operations, administration and maintenance (OAM), a supervisory function by Simple Network Management Protocol (SNMP) and setting, monitoring and control functions by Web-based Local Terminal

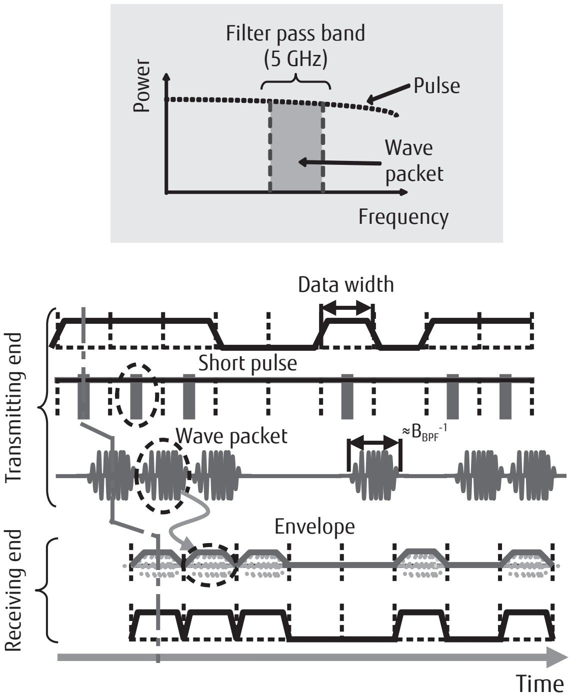


Figure 2
Principle of impulse radio technology.

Table 1
Major specifications of E-band impulse radio equipment.

Item	Specifications
Modulation/demodulation scheme	ON-OFF modulation, envelope detection
Frequency band	71–76 GHz, 81–86 GHz
Transmission capacity	3.6 Gb/s
Transmission power*	+17 dBm
Propagation distance	Up to 3 km
User interface	Optical I/F (10GbE, GbE, CPRI)
OAM	SNMP Local terminal

*Peak value

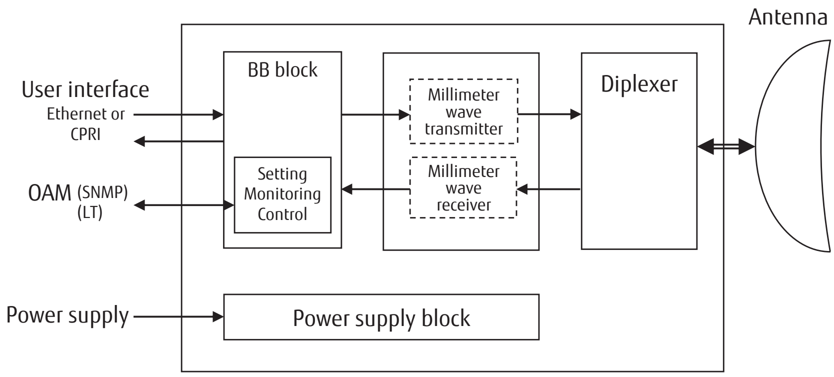


Figure 3
Block diagram of E-band impulse radio equipment.

Figure 4
Appearance of E-band impulse radio equipment.

(WebLT) are provided.

The maximum digital transfer rate is 3.6 Gb/s and the path distance is up to 3 km depending on the propagation conditions.

The appearance of the E-band impulse radio equipment is shown in **Figure 4**. The impulse radio equipment is an all-in-one integrated transmitter/receiver intended for outdoor use that includes a user interface. Adopting the impulse radio technology has allowed for a simpler circuit configuration, which has led to the realization of a compact, lightweight and low-power consumption equipment and helps reduce the cost of capital expenditure (CAPEX) and operational expenditure (OPEX). Various types of parabolic antennas directly connected with radio equipment are selectable depending on the path distance and V/H-polarization is also selectable.

3.2 Evaluation of characteristics

A prototype piece of impulse radio equipment was used to evaluate the characteristics as described below.

1) Evaluation of characteristics by indoor propagation

The radio equipment is connected to L2 switches at input and output terminals. A video from a PC is inputted to the sending radio equipment via the L2 switch facing the PC, transmitted to the receiving radio equipment, and outputted to a display via the L2 switch facing the display using High-Definition Multimedia Interface (HDMI)-Ethernet conversion. The sending radio equipment receives a video through the L2 switch, which is located between the PC and the sending radio equipment, and sends video data to the receiving radio equipment. The receiving radio equipment receives the video data and sends the video data to a display through the L2 switch, which is located between the receiving radio equipment and the display. In the same way, a real-time video taken with a camera and a real-time streaming video taken with a PC are also inputted to the sending radio equipment and outputted to a display. Moreover, data transmission of multiple gigabit Ethernet packets using packet transmission measuring equipment were conducted as a large-capacity transmission experiment. The results showed that multiple gigabit Ethernet transmissions were confirmed without any image distortion or packet loss and with low latency.

2) Evaluation of characteristics by outdoor propagation and environmental data

A prototype piece of impulse radio equipment was used to evaluate the characteristics with a transmission distance of approximately 1.2 km. A 60-cm diameter antenna was used, the interface was 10 Gigabit Ethernet and the transmission capacity was 2.8 Gb/s with packet transmission. While the direction adjustment at installation was tight in angle with the antenna half beam width of 1 degree or smaller, adjustment was relatively easy in demonstration. This verified the practicability of the antenna alignment. A rain gauge and thermometer were installed to measure the rainfall and temperature at the same time as measuring the received signal level (RSL) and bit error rate (BER) of the radio link. As a result, we have confirmed that the rain attenuation is nearly equal to the system design calculation value.

3) Evaluation of connection with mobile base station

A prototype piece of impulse radio equipment was used in the CPRI link between the radio equipment control (REC) and radio equipment (RE) of a mobile base station to evaluate interconnection. The results showed no BER degradation and the equipment's usability as a backhaul of a mobile base station was confirmed.

4. Application examples

Figure 5 shows an image of application examples of the E-band impulse radio equipment.[6)]

1) Live broadcast from the scene

When conducting a live broadcasting of events

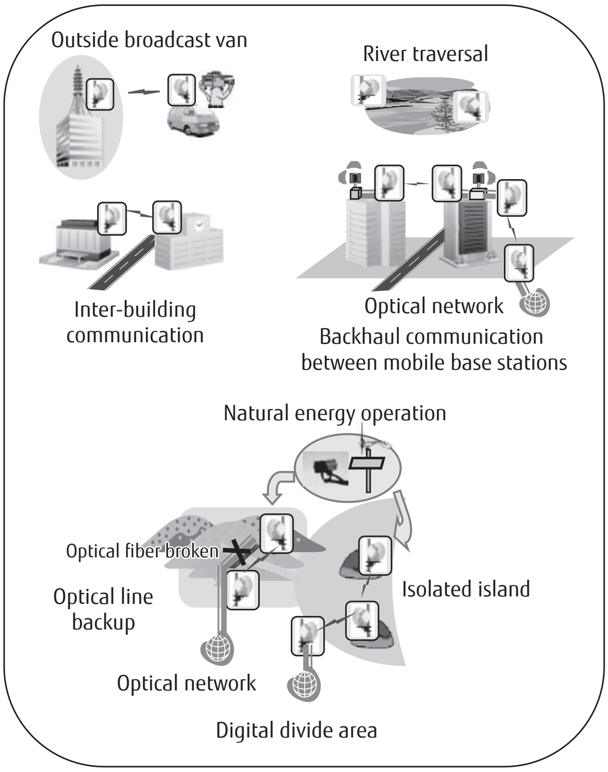


Figure 5
Image of application examples of E-band impulse radio equipment.

or such like, use of the E-band impulse radio equipment as a temporary link eliminates the need for installing an optical cable from the broadcasting site to the communication station building. In addition, large-capacity transmission allows uncompressed high-definition video signals to be transmitted with low latency.

2) Traversal of river or bay

In a traversal of a river or bay where it is difficult to install an optical fiber, use of E-band impulse radio equipment allows a high-speed network that does not require a bridge nearby or large detour instead of optical fiber link.

3) Inter-building communication (local area network in enterprise, university, etc.)

To construct an inter-building local area network in places such as enterprise and university areas, E-band impulse radio equipment allows a high-speed network instead of optical fiber link without construction across the road.

4) Communication between mobile base stations

In the case of newly introducing a mobile network such as 4G/LTE/WiMAX backhaul and small cell or picocell interconnect communication, use of E-band impulse radio equipment could be beneficial in a number of ways, including rapid deployment and relatively low establishment cost in comparison with installing a new fiber link or the long preparation time needed for a dark fiber link.

5) Digital divide area

As measures to overcome digital divide regions where optical fibers are difficult to install due to a need to traverse valleys in the mountains or winding roads, the E-band impulse radio equipment, which offers a short installation period, can be used.

6) Quicker disaster recovery

When an optical fiber link traversing a river or bay is disconnected due to a disaster, E-band impulse radio equipment can recover traffic at an early stage.

7) Use of solar power panel

E-band impulse radio equipment can be operated using a solar power panel due to its low power consumption.

5. Conclusion

Large-capacity wireless transmission of 3.6 Gb/s using impulse modulation technology in the millimeter-wave band (E-band) has been realized. This radio communication system can be widely applied in the field of Ethernet (10GbE or GbE) or CPRI network. It means that mobility as one of the characteristics of radio communication can make network design more flexible. In the future, our development will be focused on diversifying the user interface and using self-power-feeding systems by natural energy.

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