

## Satellite Communications using Ultra Wideband (UWB) Signals

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**Abstract** *This paper considers the satellite communication systems using the multiband UWB signal format. For terrestrial short-distance high-speed communications, the multiband UWB scheme have been proposed in IEEE 802.15 TG3a and discussion is ongoing at the standardization body. In the multiband UWB scheme, frequency hopping is adopted over 3.1 - 10.6 GHz, which is regulated by the FCC (Federal Communications Commission) of the U.S.A., and the bandwidth of one hopping spectrum (subband) is about 500 MHz. Multiband technology inherently has suitable characteristics for the terrestrial UWB such as applicability to variable transmission rates, avoidance of harmful interference to other systems, simple localizability of frequency allocations, and so forth. This paper presents a satellite communication downlink employing the multiband UWB signal transmission. The total bandwidth is assumed to be 500 MHz in the allocation of the satellite downlink and it is divided into multiple subbands. We report the initial results of the study on the link budget calculation and the estimation of the signal transmission speed assuming the multiband UWB signal transmission from a GSO (GeoStationary Orbit) satellite to the earth's surface.*

### 1. Introduction

The FCC (Federal Communications Commission) has defined the characteristics of the UWB devices to promote the commercial use [1]. According to the FCC regulations, the emission level is restricted to as low as -41.3 dBm/MHz in 3.1 GHz – 10.6 GHz as described in the next section. Thus, although the occupied bandwidth of the UWB signal is very wide, the spectrum power density is very small. Therefore, the UWB system is capable of suppressing interference to and from other narrowband systems. It is said that the UWB signal can be overlaid on frequency currently used by the other narrowband systems, and the effective use of frequency may be realized.

Although discussion of the UWB has mainly focused on the terrestrial short distance communication, the UWB could be radiated from satellites to the earth as one type of satellite services (“Satellite UWB”). In a satellite communication that overlays the UWB signal on a frequency band currently used by the existing satellite communications, a new communication channel can be added without an assignment of new frequency to the existing satellite communications.

Some UWB systems use pulse communication technology, and these systems have a simple configuration of a transmitter and a receiver. So it is expected a terminal consumes relatively low power in comparison with other wireless communication systems, and a small-sized terminal powered by a small battery could be developed. The devices for the terrestrial UWB system would be low cost due to mass-production. By incorporating the same system in satellite

communication, it is possible to use the devices of the terrestrial UWB system, and the cost of the terminal for the satellite UWB system is reduced.

The IEEE 802.15 High Rate PHY Task Group (TG3a) for Wireless Personal Area Networks (WPANs) is working to define a project to provide a higher speed PHY enhancement for applications including imaging and multimedia communications. The multiband UWB scheme has already been proposed in the working group.

In this paper we examine whether sufficient transmission speed is obtained or not by the satellite UWB, assuming mono-pulse type PAM(Pulse Amplitude Modulation) modulated signal and the multiband UWB scheme proposed in the standardization body. As the result of the discussion we show the satellite UWB has preferable properties for the development of new satellite communications.

### 2. FCC Regulation on UWB

U.S. FCC has already regulated the UWB system, including the operating restrictions, authorizing the use of UWB devices on an unlicensed basis. Various applications have been considered, such as communications, measurements, radar systems, and so forth. The followings are the spectrum and emission limitations of the regulations for the handheld UWB devices, which are typical communication devices using the UWB signal.

**Bandwidth :**

Fractional bandwidth equal to or greater than 0.2, or bandwidth equal to or greater than 500 MHz.

**Radiated emissions :**

0.96 - 1.61 GHz	<	-75.3 dBm/MHz
1.61 - 1.99 GHz	<	-63.3 dBm/MHz
1.99 - 3.1 GHz	<	-61.3 dBm/MHz
3.1 - 10.6 GHz	<	-41.3 dBm/MHz
10.6 GHz -	<	-61.3 dBm/MHz

**Peak level of emissions :**

The peak level of emissions contained within a 50 MHz bandwidth centered on the frequency at which the highest radiated emission is 0 dBm EIRP.

**3. Satellite UWB**

The satellite UWB system in this paper is a fixed satellite system, which employs a UWB type signal for the downlink transmission. Figure 1 shows the conceptual view of the satellite UWB system using the Ku-band. The UWB signal is usually characterized by transmitting very short monocycle wavelets or pulse-modulated carrier. As presented in Section 2, the signal bandwidth of the terrestrial UWB device is very wide such as more than 500 MHz. The assumed bandwidth used in the satellite UWB system is 500 MHz.

The satellite UWB has suitable characteristics for exploring new satellite services from the following perspectives :

- The UWB signal can be overlaid on the existing narrowband spectrum. This is expected to contribute to increasing spectrum efficiency of satellite systems.
- The terrestrial UWB device can be utilized for the satellite UWB application, which would reduce the cost of the satellite system. The terrestrial UWB device is expected to become very popular, and mass-production of the terminal will greatly reduce the production cost of the hardware.

**4. Link budget**

In the satellite UWB system, if the power transmitted from a satellite to the earth is at the same level as the terrestrial UWB device, the received signal on the earth

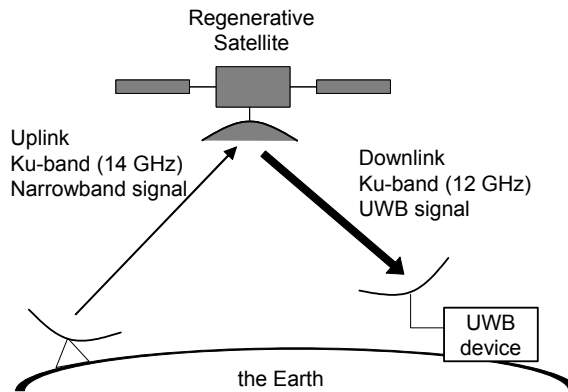


Fig. 1. Conceptual view of satellite UWB system using Ku-band.

is very low, and the transmission speed is limited very low. Therefore, higher power, which is comparable to that with existing satellite transponder, is assumed to be transmitted from the UWB satellite. This paper assumes the satellite transmission power as 108 W (20.3 dBW) and the transmitting satellite antenna diameter as 1.27 m. When these transmission characteristics are adopted by the satellite to transmit the UWB signal to the earth, radiated EIRP from the satellite is much greater than that of the terrestrial UWB. But the signal power density received at the earth's surface is assumed comparable to or smaller than that of the terrestrial UWB device as described below.

The link budget of the downlink are estimated in the case where 500 MHz in the Ku-band is assumed as the downlink spectrum. Table 1 summarizes the downlink link budget of the system. The free-space path loss for the distance of 3 m at the center frequency of 6.85 GHz, a typical value for the terrestrial UWB device using the

Table 1. Downlink link budget.

Center frequency	12	GHz
Bandwidth	500	MHz
Transmission power	20.3	dBW
Satellite antenna diameter	1.27	m
Satellite antenna gain (efficiency = 60%)	41.8	dBi
EIRP	65.1	dBm/MHz
Link margin	5	dB
Rain margin	3	dB
Path loss to the earth's surface (at 12 GHz)	205.2	dB
Power density at the earth's surface	-148.1	dBm/MHz

3.1 - 10.6 GHz spectrum, is around 60 dB. In the terrestrial UWB device, the power density, which is given by [EIRP]-[Path Loss] in dB scale, at a distance of 3 m from a transmitter is -101.3 dBm/MHz. The table shows that the power level of the satellite UWB signal received at the earth's surface (-148.1 dBm/MHz) is much smaller than the signal level at the distance of 3 m of the terrestrial UWB. Therefore, the other service would not be affected by the satellite UWB system.

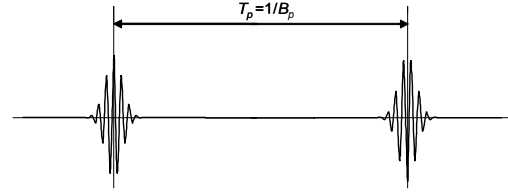


Fig. 2. Symbol of  $M$ -ary PAM.

## 5. Throughput analysis

### 5.1. $M$ -ary PAM UWB

The  $M$ -ary PAM(Pulse Amplitude Modulation) is a modulation scheme where information is modulated with  $\pm M$  amplitude variations. The pulse has a short duration, and its energy concentrates within the bandwidth of the satellite downlink, in the satellite UWB (Fig. 2).

Results of the research have been reported for the communication performance of the terrestrial UWB device. Here, the performance is discussed using the approach presented in Ref. [2].

A coherent detection is assumed as the demodulation scheme. The symbol error probability  $P_M$  of the  $M$ -ary PAM is given by

$$P_M = \frac{M-1}{M} \operatorname{erfc} \left( \sqrt{\frac{3}{M^2-1} \times \frac{E_s}{N_0}} \right). \quad (1)$$

And the probability of a bit error  $P_b$  is [3]

$$P_b = \frac{1}{k} P_M, \quad (2)$$

where  $k$  is the number of bits, which are transmitted in one symbol, i.e.  $k = \log_2 M$ . Using Eqs. (1) and (2), the required  $E_s/N_0$ , a signal power per symbol to noise power density ratio, can be calculated. Table 2 shows the required  $E_s/N_0$  for the bit error rate of  $10^{-3}$ .

Table 2. Required  $E_s/N_0$  for  $M$ -ary PAM.

$M$	Required $E_s/N_0$ [dB]
2	7
4	13.75
8	19.77
16	25.5

On the other hand,  $E_s/N_0$  is also presented by the following equation.

$$E_s/N_0 = P_{ave} T_p / N_0 = [P_{sd} / N_0] \times [B_s / B_p], \quad (3)$$

where,

- $P_{ave}$ : Average received power,
- $T_p$ : Pulse repetition period,
- $P_{sd}$ : Average power spectral density,
- $B_s$ : Equivalent occupied bandwidth, and
- $B_p$ : Pulse repetition frequency.

Equation (3) indicates that the pulse repetition period  $T_p$  becomes larger as required  $E_s/N_0$  becomes larger. Taking the receiver noise figure  $N_F$  into consideration, the pulse repetition frequency  $B_p$  can be written as

$$B_p = [P_{sd} / N_0] \times B_s / N_F / [E_s / N_0]. \quad (4)$$

Table 3. Achievable throughput of  $M$ -ary PAM UWB [bit/s].

	2-ary	4-ary	8-ary	16-ary
0 [dBi] (Isotropic antenna)	9.96k	4.21k	1.58k	563
5.0 [dBi] (Patch antenna)	31.5k	13.3k	4.99k	1.78k
19.8 [dBi] (10 cm dish)	951k	402k	151k	53.7k
33.7 [dBi] (50 cm dish)	23.3M	9.87M	3.70M	1.32M
39.8 [dBi] (1 m dish)	95.1M	40.2M	15.1M	5.37M

Using  $\log_2 M$  equal to the number of bits transmitted by one pulse, the achievable throughput  $R$  can be calculated as

$$R = B_p \times \log_2 M \quad (5)$$

Assuming free-space propagation between a satellite UWB transmitter and a receiver, and also assuming  $P_{sd}=-208.1$  [dBm/Hz],  $B_s=500$  [MHz] from Table 1,  $N_0=-174$  [dBm/Hz] at room temperature (17[°C]), and  $N_F=6$  [dB], the achievable throughput can be calculated from Eqs. (4) and (5). Table 3 summarizes the achievable throughput of the  $M$ -ary PAM UWB transmitted from the satellite using the Ku-band.

### 5.2. Multiband UWB

In the terrestrial UWB, multiple transmission schemes adopting frequency-hopping over 3.1 - 10.6 GHz have been proposed at IEEE 802.15 TG3a. The mission of the standardization body is to define the physical layer specification for WPANs. Multiband UWB is a frequency-hopping scheme and has the feature of bit rate scalability with the occupied frequency.

Figure 3 shows an example of the symbol structure of the multiband UWB [4]. The symbol pulse consists of subpulses. And the subpulses are hopping over multiple frequency bands. Data is encoded into the sequence

Table 4. Required  $E_s/N_0$  for  $S$  - bands UWB.

$S$	Required $E_s/N_0$ [dB]
4	14.5
8	18

pattern of bands and phase information of the subpulses. The number of bits ( $N$ ) transmitted by one symbol is

$$N = \log_2({}_S C_B \times {}_T P_B \times 2^{BP}), \quad (6)$$

where,

- $S$ : Number of frequency bands,
- $T$ : Number of subpulse time slots in a pulse,
- $B$ : Number of non-zero entries, and
- $P$ : Number of polarity bits.

${}_S C_B$  and  ${}_T P_B$  indicate combination and permutation, respectively. In Eq. (6), data of  $\log_2({}_S C_B)$  and  $\log_2({}_T P_B)$  bits are transmitted by the sequence pattern, and data of  $\log_2(2^{BP})$  (=BP) bits are transmitted by the phase information of the subpulses.

Assuming  $S=T=B$ , Eq. (6) can be written as follows;

$$N = \log_2(S!) + SP \quad (7)$$

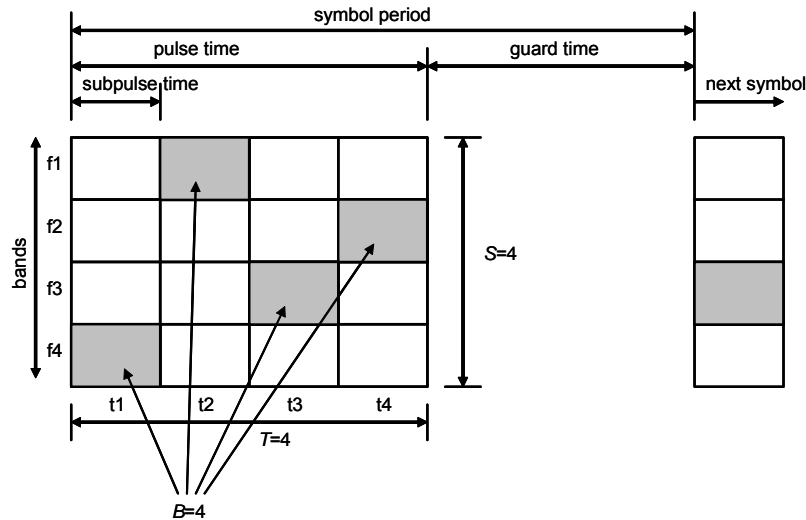


Fig. 3. Example of symbol structure of multiband UWB.

Upper bound of the subpulse error probability  $P_s$  of multiband UWB, which uses  $S$  bands, is given by

$$P_s = 4(S - 1)Q\left(\sqrt{\frac{2E_{sp}}{N_0}}\right), \quad (8)$$

where,

$S$ : Number of frequency bands,  
 $E_{sp}$ : Energy per subpulse, and  
 $N_0$ : Noise spectral density.

The relation between the energy per subpulse  $E_{sp}$  and the energy per symbol  $E_s$  is

$$E_s = E_{sp} \times S. \quad (9)$$

Using Eqs. (8) and (9), the required  $E_s/N_0$  can be calculated. Table 4 shows the required  $E_s/N_0$  for the subpulse error rate of  $10^{-3}$ .

Similar to the  $M$ -ary PAM, the pulse repetition frequency  $B_p$  can be written as

$$B_p = [P_{sd}/N_0] \times B_s / N_F / [E_s/N_0]. \quad (10)$$

Because the number of bits in one symbol is expressed by Eq. (7), the achievable throughput  $R$  can be calculated as

$$R = B_p \times [\log_2(S!) + SP]. \quad (11)$$

Table 5. Achievable throughput of  $S$ -bands UWB [bit/s].

	4-bands		8-bands	
	BPSK	QPSK	BPSK	QPSK
0 [dBi] (Isotropic antenna)	15.2k	22.3k	18.4k	28.4k
5.0 [dBi] (Patch antenna)	48.1k	70.5k	58.3k	78.3k
19.8 [dBi] (10 cm dish)	1.45M	2.13M	1.76M	2.36M
33.7 [dBi] (50 cm dish)	35.6M	52.3M	43.2M	58.1M
39.8 [dBi] (1 m dish)	145M	213M	176M	236M

Using the same assumptions as the  $M$ -ary PAM,  $P_{sd}=-208.1$  [dBm/Hz],  $B_s=500$  [MHz],  $N_0=-174$  [dBm/Hz] and  $N_F=6$  [dB], the achievable throughput can be calculated from Eqs. (10) and (11). Table 5 presents the achievable throughput of the  $S$ -band UWB transmitted from the satellite using the Ku-band.

### 5.3. Analysis

Table 3 shows that the transmission speed of the binary PAM up to 950 kbit/sec can be realized using a very small user antenna such as 10 cm. Moreover, when a larger antenna is utilized, considerably larger throughput is realized.

In Table 4, by adopting the multiband UWB scheme, the satellite UWB transmission speed of over 1 Mbit/sec can be achieved using a 10 cm dish antenna. Throughput over 100 Mbit/sec is realized by utilizing a 1 m dish antenna.

In the process of conducting the transmission speed, the bit error rate of  $10^{-3}$  is used at  $M$ -ary PAM, and the subpulse error rate of  $10^{-3}$  is used at the multiband UWB. In the multiband UWB scheme, data is transmitted by the sequence pattern of bands and the phase information of the subpulses, so the relation between the subpulse error rate and the bit error rate is difficult to determine. As described above, in calculating the transmission speed, the error rate assumption of the  $M$ -ary PAM and the multiband UWB differs, so it is difficult to compare the transmission speeds directly. However, the satellite UWB using the  $M$ -ary PAM or the multiband UWB offers sufficiently high transmission speed, which means that these schemes are effective to fixed satellite communications.

## 6. Conclusion

Technical consideration and performance analysis are conducted for the satellite UWB system. The system could realize sufficient receive signal strength and throughput with a small antenna in addition to its inherent suitable characteristics to widely broadcast information to many users simultaneously. Satellite communication plays an important role in public communications. The satellite UWB enables new services, and is expected to open new markets.

### ACKNOWLEDGMENT

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