Intersymbol Interference Analysis of a 60 GHz-Band Compact Range Wireless Access System

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***Abstract*—A compact range wireless access system in the 60 GHz-band has been proposed for multi-Gb/s data transfer. A prototype Gigabit Access Transponder Equipment was made to evaluate the system performance of bit-error rate and signal-to-noise ratio. An error-free communication zone up to 11 m is available by adopting the 32×32 and 64×64-element waveguide slot arrays in the transmitter. However, the BER degrades especially for the propagation distance less than 1 m. In this study, the concept of intersymbol interference is introduced in the antenna and propagation field for the first time. An equivalent baseband communication system is newly proposed to evaluate the wireless channel including antennas. The ISI as well as BER for the circular aperture antenna is theoretically analyzed as a function of propagation distance.**

***Index Terms*—intersymbol interference, compact-range communication, large arraye antenna, symbol rate, delay spread, waveform shaping filter.**

I. Introduction

A novel compact-range wireless access system in the 60 GHz-band is proposed to realize multi-Gb/s data transfer. A GATE (Gigabit Access Transponder Equipment) together with the mobile terminals enables the access to a cloud service. As illustrated in Fig. 1, the 60 GHz-band GATE is to be equipped as the fixed terminal in public areas such as in corridors and escalators in stations et al. When a user holding a mobile terminal passes through a GATE, the gigabit access is available. A large antenna adopted in the access point generates a quasi plane wave in its near-field region. For example, the $(25\lambda)^2$ aperture antenna will provide a stable and large signal-reception zone, with an area proportional to the antenna aperture and a communication distance up to 10 m. In addition, the distance-independent line of sight (LOS) and multipath-free propagation environment enables the single carrier transmission with disregard to fading and sophisticated equalization technique. Differently from the conventional mobile and fixed wireless access system which generally operate in the far-field region, this compact range communication system suggests the potential of a new wireless communication as the third category.

II. System Evaluation of a Prototype Gate

A prototype GATE including a baseband (BB) module [1] and a radio frequency (RF) front end [2] was constructed for demonstration. This system utilizes a 2.16 GHz frequency bandwidth ranging from 59.40 to 61.56 GHz. The channel-bit rate is 3.456 Gb/s for the π/2-shift quadrature-phase-shift keying modulation (QPSK). By adopting a low-density parity-check (LDPC) code with a 14/15 rate [3], the maximum data rate of 3.1 Gb/s is realized in an efficient way.

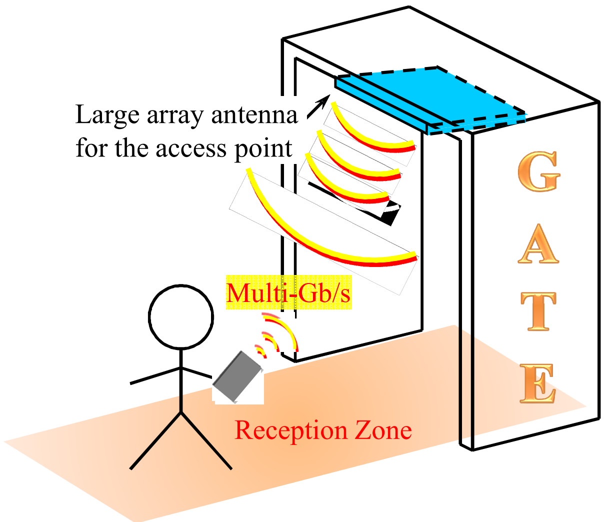


Fig. 1. 60 GHz-band GATE for compact-range wireless access system.

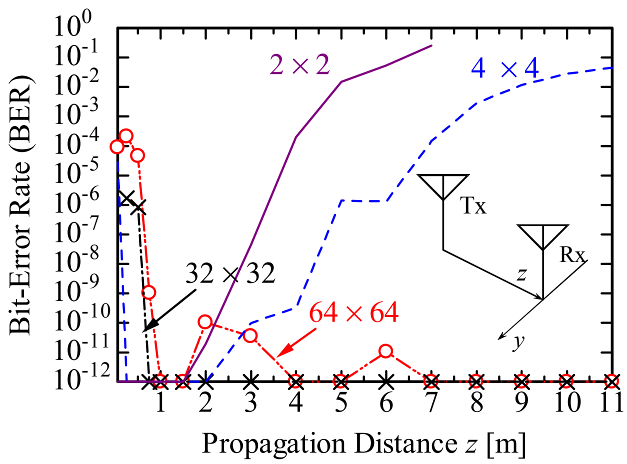


Fig. 2. Measured BERs with LDPC as a function of propagation distance for various array antennas

The circularly-polarized waveguide slot arrays of various element numbers were designed and fabricated [4]. The large antennas represented by 32×32 and 64×64-element arrays and the small antennas represented by 2×2 and 4×4-elements arrays were used in the transmitter (Tx); while an open-ended waveguide probe antenna in the V-band was used in the receiver (Rx). All array antennas have the single input, and don't enable the massive MIMO technique. The position of Tx is fixed and Rx is moved longitudinally along the *z*-direction.

The bit-error rate (BER) with LDPC for all the types of Tx antennas were measured and shown in Fig. 2 for comparison. The BERs for the small antennas degrade fast with increments in the propagation distance, due to the decrease in Rx receiving level as well the degradation in signal-to-noise ratio (SNR). An error-free communication zone up to 11 m is realized by adopting the 32×32 and 64×64-element arrays in Tx. However, the BER for the 64×64-element array degrades especially for the propagation distance less than 1 m. The reason for this unique phenomenon will be investigated in this study.

III. Analysis of Intersymbol Interference

One possibility is the introduction of extremely large antenna operating in its close near-field region. A time delay due to the signal transmitted from the antenna center and its edge can be easily imagined. Since the proposed compact-range communication system exhibits an extremely high symbol rate of 1.728 Gs/s [2], the single symbol length is only $T = 0.579$ ns. Meanwhile, the multipath richness due to a large array antenna becomes critical when it operates in its close vicinity. The delay spread degrades up to $\tau = 0.634$ ns for the 64×64-element array with an element spacing of 4.2 mm in common. Since the values of symbol length and delay spread are comparable, the intersymbol interference (ISI) [5] may easily occur within the wireless channel. The concept of ISI as well as SIR (Signal-to-Interference Ratio) which is independent of Tx power, has never been considered before in the antenna and propagation field before. It means in the antenna design for compact-range wireless access system, the antenna engineers should take into account ISI rather than the conventional evaluation indices such as gain and reflection.

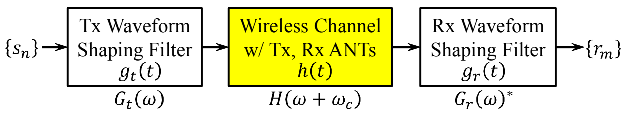


Fig. 5. Proposed equivalent baseband (BB) communication system.

Rather than the performance in BB and RF circuits, only the wireless channel including the Tx and Rx antennas is the main subject of investigation in this study. By neglecting the frequency conversion between BB and RF circuits, an equivalent BB communication system is proposed as shown in Fig. 3. The transfer function of a wireless channel is $H(\omega+\omega_c)$ and the frequency spectrum of the Tx and Rx pulse waveform shaping filters are $G_t(\omega)$ and $G_r(\omega)^*$, respectively. Here, ω_c is the center angular frequency of RF carrier.

A. Property of a Finite Inpulse Response System

For simplicity, a finite impulse response (FIR) system is considered first. The circular aperture antenna with a radius of *A*, whose impulse response can be analytically obtained, is assumed as the transmitting antenna. The ISI as a function of

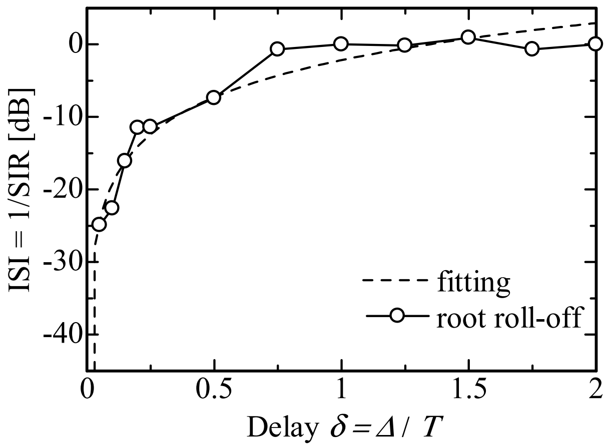


Fig. 3. Calculated intersymbol interference as a function of the dely time normalized by the symbol length *T*.

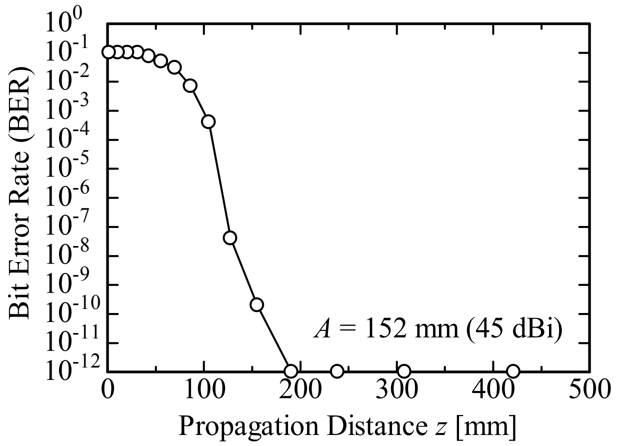


Fig. 4. Calculated bit-error rate as a function of propagation distance *z* for the circular aperture antenna with a radius of $A = 152$ mm.

delay time normalized by *T* is calculated as shown in Fig. 4, where an envelope curve is also added. Here, the delay time is a function of propagation distance *z*. In addition, when the SIR = 1/ISI is simply regarded as SNR, the BER can also be transformed from the relation of SNR-BER in our GATE system [1]. Generally, the BER behaves as the functions of both propagation distance *z* and antenna aperture size. As an example, the BER for a circular aperture antenna with a radius of $A = 152$ mm can be derived as shown in Fig. 5. Theoretically, an error-free communication is not possible when the distance between Tx and Rx antennas is shorter than 20 cm.

B. Property of an Infinite Response System

Secondly, an infinite response system (IIR) system is also investigated. The multiple reflections within or/and between the Tx and Rx antennas may degrade the intersymbol interference as well as the system performance. Fig. 6 shows the photograph of the fabricated 64×64-element array antenna used in the evaluation of Fig. 2. The antenna size is 288×290 mm^2. Since the physical antenna size is so large that the flatness and stability during the processes of etching and

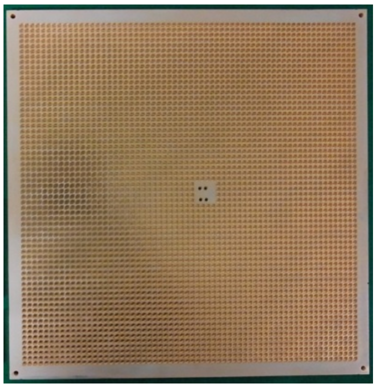
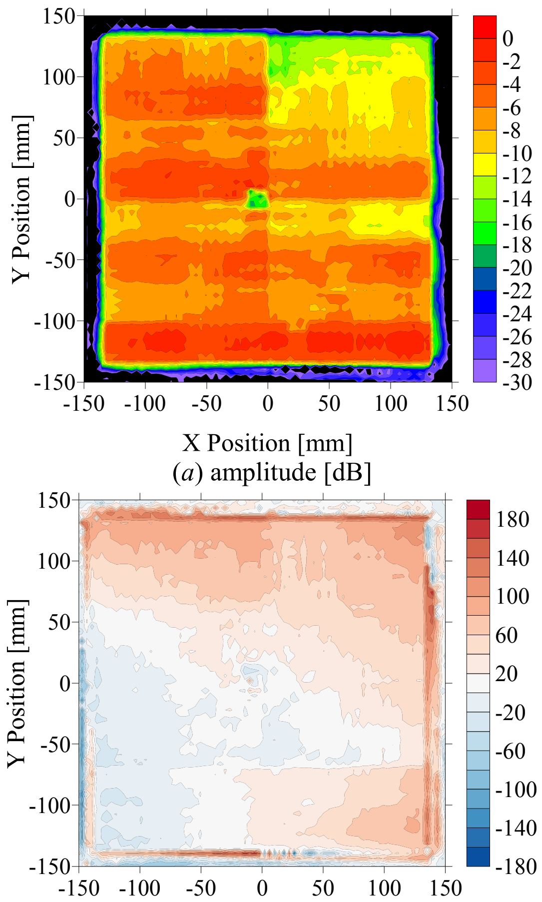


Fig. 7. Fabricated 64×64-element circularly polarized waveguide slot array antenna.



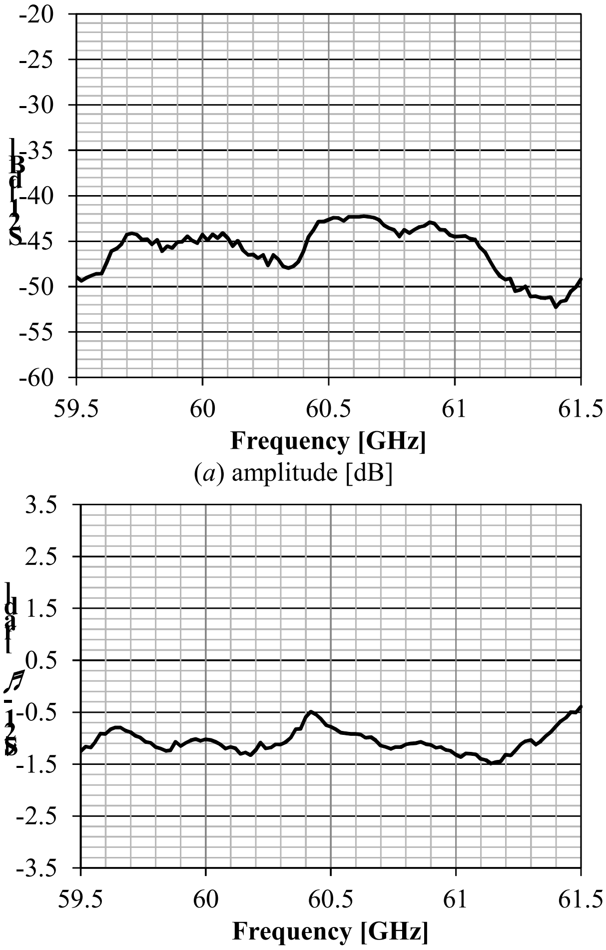
(*a*) amplitude [dB]

(*b*) phase [deg]

Fig. 8. Aperture distribution of the 64×64-element array at 60.5 GHz.

diffusion bonding remain as issues. The aperture distribution at the center frequency of 60.5 GHz is measured under a near-field measurement system and is summarized in Fig. 7, where a significant degradation in uniformity is observed.

We are going to evaluate the intersymbol interference by adopting this 64×64-element array as the transmitting antenna. This time, the transfer function is directly measured by connecting both Tx and Rx antennas to a vector network



(*a*) amplitude [dB]

(*b*) modified phase [rad]

Fig. 6. Measured transmission coefficients when the Tx and Rx antennas are seperated at 70 cm.

analyzer (VNA). Here, the distance between two antennas is fixed at 70 cm and the frequency characteristics of the transmission coefficients are summarized in Fig. 8. Large ripples as well as critical frequency dependence are observed. For simplicity, the phase delay $\omega\tau$ is subtracted from the measured raw data of phase.

Finally, the intersymbol interference (ISI) is evaluated using the transfer function $H(\omega+\omega_c)$ shown in Fig. 8. The ISI are evaluated as shown in in Fig. 9, where k is the number of symbols to calculate the interference for sufficient convergence. When the distance between Tx and Rx antennas is 70 cm, an error-free communication is not possible in our present system [1] for SIR = 10.3 dB. This result interprets the reason why the BER degrades when the propagation distance is less than 1 m as shown in Fig. 2.

In addition, the Fourier transform has been used to achieve the transmission coefficients in time domain. Their amplitudes are summarized in Fig. 10. According to our detailed investigation, the multiple reflections within the antenna feeding circuit mainly contribute to the degradation in overall antenna reflection as well as ISI especially for a short propagation distance. For the application of compact-range

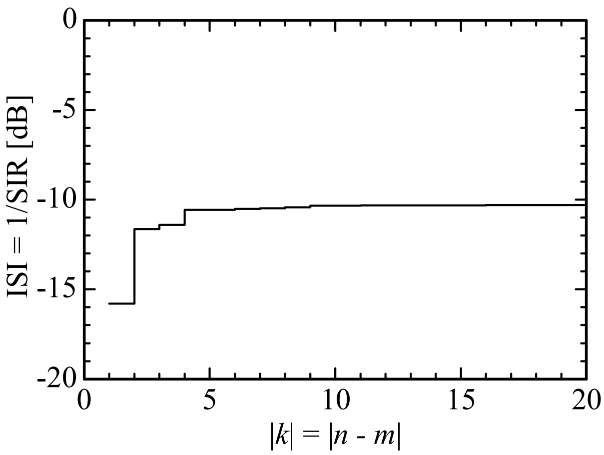


Fig. 9. Intersymbol interference evaluated as the number of symbols.

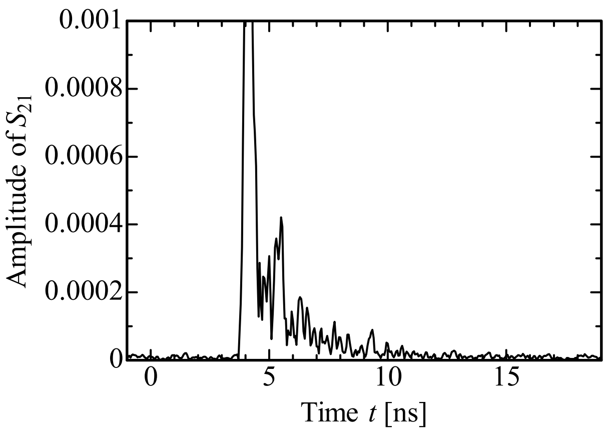


Fig. 10.

communication, sufficient suppressions of multiple reflections within or between Tx and Rx antennas are significant.

IV. CONCLUSION

The intersymbol interference of the 60 GHz-band compact range wireless system adopting a large array antenna is analyzed. An equivalent baseband communication system is proposed to evaluate the wireless channel including Tx and Rx antennas. When adopting a circular aperture antenna in Tx, the impulse response can be analytically obtained. The SIR and BER are analyzed for the aperture antenna with a radius of 152 mm, which has identical aperture with the 64×64-element array. Theoretically, an error-free communication is unavailable within the propagation distance less than 20 cm. An infinite impulse response (IIR) system taking into account the multiple reflections within antennas or those between Tx and Rx antennas is also investigated.

ACKNOWLEDGMENT

This work was conducted in part as "the Research and Development for Expansion of Radio Wave Resources" under the contract of the Ministry of Internal Affairs and Communications, Japan.

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