Loss [dB] vs. Thickness [mm]

- Microstrip Triplate
- Radiation Loss
- Waveguide
- Dielectric Loss
- Condutor Loss

Loss in Planar Structure
Single-Layer Slotted Waveguide

<table>
<thead>
<tr>
<th>Modes</th>
<th>Co-Phase</th>
<th>Alternating-Phase</th>
<th>Oversize</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-mode</td>
<td>Stacking Substrate</td>
<td>RLSA</td>
</tr>
<tr>
<td>Structure</td>
<td><img src="image1.png" alt="Co-Phase Structure" /></td>
<td><img src="image2.png" alt="Alternating-Phase Structure" /></td>
<td><img src="image3.png" alt="Oversize Structure" /></td>
</tr>
</tbody>
</table>

- **Co-Phase**: Perfect contact
- **Alternating-Phase**: Exemption of contact

Traveling wave & Series feed operation

- Post-wall planar antenna
- Backside: 75 mm
- Upper side: 27 mm

Thickness of the antenna substrate: 1.2 mm

- MMIC Package (for DC and IF)
- Connector (for DC and IF)
Fabrication Technique by Diffusion

1. Etching thin metal plates
2. Diffusion bonding
3. Complete

- Etching: high precision (20μm), Diffusion bonding: electric contact
- Expensive die is not needed, Easy to make multi-layers

Bonding
Pressure, Heat
Vacuum
# Fabrications in Various Bands

<table>
<thead>
<tr>
<th>Band</th>
<th>Picture</th>
<th>Array Size</th>
<th># of slots</th>
<th># of sub arrays</th>
<th>1dB-down gain BW</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q</td>
<td><img src="Q.png" alt="Picture" /></td>
<td>131mm x 123mm</td>
<td>20 x 20</td>
<td>2 x 2</td>
<td>5%</td>
<td><img src="Q_graph.png" alt="Graph" /></td>
</tr>
<tr>
<td>V</td>
<td><img src="V.png" alt="Picture" /></td>
<td>68mm x 68mm</td>
<td>16 x 16</td>
<td>8 x 8</td>
<td>11%</td>
<td><img src="V_graph.png" alt="Graph" /></td>
</tr>
<tr>
<td>E</td>
<td><img src="E.png" alt="Picture" /></td>
<td>45mm x 48mm</td>
<td>16 x 16</td>
<td>4 x 4</td>
<td>9%</td>
<td><img src="E_graph.png" alt="Graph" /></td>
</tr>
</tbody>
</table>
Compact-Range Wireless Access System

- Adopting large aperture antennas in the 60 GHz-band GATE;
- Communication in the near-field region (convention: far-field region);
- Reception zone: distance (~ 10 m) & cross-section area (tens of cm square);
- Antenna size: uniform intensity, wide & long zone, small interference;

**Gigabit Access Transponder Equipment**

- Large array antenna for the access point
- MMW carpet !!

*Note: 251 mm (50λ) □*
Intersymbol Interference in a 60 GHz Band Compact Range Wireless Access System adopting a Large Aperture Antenna

Mobile terminal
Gain: 3 ~ 9 dBi
HPBW: 40 ~ 60 degs.

Low-gain antenna for access point??

GATE Gigabit Access Transponder Equipment

Ando & Hirokawa Lab., Tokyo Institute of Technology
Prototype of GATE: BB module + RF front end + Antenna;
- Maximum data rate is 3.1 Gbit/s by QPSK;
- Adopting a rate-14/15 low-density parity-check (LDPC) code;
- 3 min. measurement, error-free is indicated by BER = 10⁻¹²
- Stable reception zone related to the antenna size is realized;
- Tx ANT (CP): different sizes; Rx ANT (LP): open-ended WG;
- Tx ANT is fixed, and the position of Rx ANT is changed.
- Large ANT: long & wide reception zone (multipath-free)
- Problem: degradation for short distance (< 1 m)
38GHz 1Gbps Outdoor system
Colaboration for 38GHz outdoor system

1bpsに対応 超高速ベースバンドSoC

1Gbps対応 超高速ベースバンドSoC

ローカル＆イメージ 抑圧用BPF追加

飛越結合型帯導波管BPF

2W級ミリ波帯高出力増幅器

高精度な変復調特性を 送受通で維持

ミリ波帯InP低雑音増幅器

飛越結合型帯導波管BPF

全温度範囲にて所望のRF対向生BER特性を確保

目標の受信レベル範囲にて1Gbps達成！
Tokyo Tech MMW Model Network

Rain rate, Rx Level, BER are recorded every 5 seconds

<table>
<thead>
<tr>
<th>Year</th>
<th>2008~</th>
<th>2010~</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>25GHz</td>
<td>38GHz</td>
</tr>
<tr>
<td>Trans. Speed</td>
<td>80Mbps</td>
<td>1Gbps</td>
</tr>
</tbody>
</table>

Link 1 (595m)
Link 2 (538m)
Link 3 (1020m)
Link 4 (331m)
Link 5 (617m)
Link 6 (238m)
Link 7 (493m)
Link 8 (223m)
Link 9 (77m)
Monitoring System

- Tipping-bucket rain gauge

- Monitoring PCs
  - Rain rate
  - Rx level
  - BER
  (every 5sec)

- PHS Monitoring PC
  - Throughput

- Wireless (25GHz)
- MMW Model Network
- SW
- LAN
- RS232-C
Comparison to Prior Researches – Rain Rate

**Backgrounds**

More and more base stations

The link length shorter than 1km (in most cases)

Heavy rain & Short distance

- Conventional propagation study: assuming weak and uniform rain in large area. Diversity effects for macro scale.
- Focusing on the behavior of *localized rain*, we may obtain *the diversity effect even in small mesh networks*.
Frequency Distribution of Rainfall

- Rainfall distribution classified according to rain attenuation

**Real Case (Localized Rainfall)**

**Ideal Case (Uniform Rainfall)**

Localized Behavior of Rainfall
Intensive Heavy Rain

- Recent metropolitan intensive heavy rain is localized.
- Densely located millimeter-wave line can be better rain gauge.
Quantitative analysis of rainfall variability

\[ \gamma(d) = \frac{1}{2N} \sum_{x_2-x_1 \approx d} \left\{ [z(x_2) - z(x_1)]^2 \right\} \]

where \( N \) denotes the number of pairs \((x_1, x_2)\) separated by a distance equal to \( d \)
Correlation vs. Variogram of Rainfall

Spatial Correlation of rainfall

Variogram of rainfall

<table>
<thead>
<tr>
<th>Distance [km]</th>
<th>Correlation</th>
<th>Variogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>R ≥ 20 [mm/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R ≥ 10 [mm/h]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 &gt; R &gt; 0 [mm/h]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3 Years (2010/4-2012/5), 1-min data
Variogram of Rainfall, Attenuation

Variogram of **average rain rate** between links

\[
\text{Rain}_{AB} = \text{mean}(\text{Rain}_A, \text{Rain}_B)
\]

Variogram of **rain attenuation** between links

\[
\text{Att}_{AB} = \text{mean}(\text{Att}_A, \text{Att}_B)
\]
40GHz band wireless mesh network and proactive re-routing against localized strong rain

Network throughput degradation <10%
Link Down Rate at Nodes

LDR[\%] = \frac{\text{Total down time}}{\text{Total monitoring time}} \times 100

1 year data (2010/3-2011/2)
Background

In millimeter-wave band

- Propagation loss is large
- High power devices are expensive

Directive antenna

Horizontal plane:
- Beam switching

Vertical plane:
- Cosecant pattern
8-Way Butler Matrix

Port #1
input
(-22.5 deg)

Port #2
input
(+157.5 deg)

Insertion Loss
Measured
< 0.25 dB at 22 GHz
Calculated
< 0.15 dB at 22 GHz
Radiation pattern in the H-plane

(a) Calculated directivity

- Ideal power distribution
- Measured power distribution

8-element infinitesimal dipole array excited by the 8-way Butler matrix in calculation

(b) Measured radiation pattern

Relative amplitude

- Port #1 input
- Port #2 input
- Port #3 input
- Port #4 input
- Port #5 input
- Port #6 input
- Port #7 input
- Port #8 input