300 Mbps Downlink Communications from 50kg Class Small Satellites

Hirobumi Saito
Japan Aerospace Exploration Agency (JAXA),
Institute of Space and Astronautical Science (ISAS)

Naohiko Iwakiri, Atsushi Tomiki, Takahide Mizuno, Hiromi Watanabe,
Tomoya Fukami, Osamu Shigeta, Hitoshi Nunomura, Yasuaki Kanda,
Kaname Kojima, Takahiro Shinke, and Toshiki Kumazawa
Contents

1. Purpose : 320Mbps down link for small sat
2. Onboard segment: high effiency transmitter. small antenna
3. Ground segment : 3.8m S/X band antenna powerful receiver
4. Total simulation : SPW software + link calculation
5. EM test finished. FM maunufacturing now.
Limits of Small Satellites for Earth Observations

- Mass Limit (<100kg), Power Limit (<100W)
  - Telescope Resolution (5m vs. 0.5m)
  - Down link Speed (10Mbps vs. 800Mbps)

What is the Bottleneck of Down Link Speed?
- Power!
Down link bit rate VS. satellite mass for low earth orbit.

Hodoyoshi #4 (2014)
High Speed Down Link
for Small Sat

• Purpose of This Research:
  High-speed Down Link System
  with Low Power Consumption

—Goal

  50kg Sat @ 600km orbit
  DC power < 20W, 320Mbps
  Small Ground Antenna < 4m
System block diagram of high-data-rate downlink.

- **Satellite Transmitter**
  - CCSDS-Formated Data
  - FPGA
    - I/Q Map
    - Pulse Shaping Filter
    - Pre-Distortion
    - D/A
    - Low Pass Filter
    - I-Q Mod
    - UP-Con
  - Cal A
  - Cal B
  - Cal C
    - RF Amp

- **Data**
  - Ground Demodulator
    - Turbo equalizer, Turbo decoder
    - Small S/X dual band parabolic antenna

- Simple digital circuit X2.5 oversampling with analog filter
- Simple memoryless look – up - table
- GaN Amplifier high efficiency & small distortion
- Small X band antenna
## Performance of High - Data - Rate Down Link

<table>
<thead>
<tr>
<th>Instruments</th>
<th>Mass (g)</th>
<th>Power (W)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-board</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmitter</td>
<td>1330</td>
<td>18</td>
<td>16QAM, 348Mbps GaN Power Amp.</td>
</tr>
<tr>
<td>Antenna</td>
<td>69</td>
<td>0</td>
<td>13.5 dBi</td>
</tr>
<tr>
<td>Iso-flux</td>
<td>150</td>
<td>0</td>
<td>5dBi(60°), -2dBi(0°)</td>
</tr>
<tr>
<td>Ground Station</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antenna</td>
<td>3.8m Dia. S/X Cassegrain, 47.5dBi(X), 36dBi(S), Sys. Noise temp. 100K</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demodulator</td>
<td>100Msps, (348-144Mbps), 16QAM, QPSK SCCC Turbo Equalizer CCSDS 131.2-B-1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
High-Speed 16QAM Down Link with Nonlinear Amplifier

High efficiency RF amplifier may degrade bit error rate.
Digital Pre-distortion compensates Nonlinearity

Pre-Distortion

Nonlinear RF amplifier

Pulse Shape Filter

AM compensation

PM compensation

Mod

AM - PM

Small Distortion

RF out

14bit

AM-AM LUT

AM-PM LUT

Coordinate transformation
Rectangular to Polar

Coordinate transformation
Polar to Rectangular
# X Band Power Amplifiers

<table>
<thead>
<tr>
<th>Amplifier</th>
<th>GaAs AB</th>
<th>GaN AB</th>
<th>GaN F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Power</td>
<td>38dBm</td>
<td>37dBm</td>
<td>36dBm</td>
</tr>
<tr>
<td>Maximum Gain</td>
<td>10dB</td>
<td>11dB</td>
<td>12dB</td>
</tr>
<tr>
<td>Maximum PAE</td>
<td>37%</td>
<td>46%</td>
<td>60%</td>
</tr>
<tr>
<td>PAE at 3dB OBO</td>
<td>23%</td>
<td>36%</td>
<td>38%</td>
</tr>
<tr>
<td>Maximum Phase Shift</td>
<td>10°</td>
<td>-2°</td>
<td>-34°</td>
</tr>
</tbody>
</table>

*Newly Developed 2W GaN HEMT AB Class*
AM/AM

Output [dBm]

Input [dBm]

O.P.

GaAs (AB)

AM/PM

Phase Shift [degree]

Input [dBm]

O.P.

Without Pre-distortion

IQ Constellation

GaN (AB)

Output [dBm]

Input [dBm]

O.P.

GaN (F)

Output [dBm]

Input [dBm]

O.P.
EM of 348 Mbps Transmitter

Modulation: 16QAM/QPSK
Mass : 1330g
RF Power: 2W
DC Power : 20W
AM-AM, AM-PM Characteristics

X-band Transmitter (EM)

Efficiency (PAE) 47% (PA, GaN-HEMT)
Output Backoff 2dB
Phase Shift  2 deg (average)

![Graph of EM Input-Output characteristics](image1)

![Graph of EM Input-Phase shift characteristics](image2)

Average power
16QAM I/Q Constellation @ 33dBm
(EM RF block)

Without Predistortion

With Predistortion

Inner Points
Improved
By predistortion

(a) Without pre-distortion
(b) With pre-distortion
Bit Error Rate v.s. Eb/No

EM RF Block, uncoded 16QAM

When Uncoded BER < $5 \times 10^{-2}$ at $E_b/N_0 = 10$ dB, SCCC + Turbo Equalizer / Deoder achieves $\text{BER} < 10^{-6}$.
Onboard Small Antenna

Body-Fixed Medium Gain Antenna

14 dBi, 68g

14 dBi, 68g, 7x7cm

For 320Mbps high bit rate mode,
Satellite points earth station
Onboard Small Antenna

Body-Fixed Iso-flux Antenna

5dBi max, 150g

Quadrafilar helix
150g, D=10mm, H=20m

For Earth-Pointing Satellite, Antenna pattern compensates range variation
Ground Antenna

3.8m Ground Antenna for S / X Band

S band : Telemetry & Command
X band : Mission Data Down Link (320Mbps)

Ring-Focus Cassegrain
Developing 400Mbps 16QAM ground receiver
Block diagram of high-data-rate downlink and ground receiver

Transmitter

- Packet generator
- SRRC filter
- Pre-distortion
- Power amplifier
- RF BPF
- \( a_i \)

Receiver

- Complex NCO
- Frequency tracking loop (FTL)
- Loop filter
- Phase detector
- Signal resampler
- Matched filter
- \( r_n \)
- SCCC turbo equalizer
- Timing tracking loop (TTL)
- Loop filter
- Timing detector
- \( \hat{a}_j \)

Equalizer

Inner Decoder

Outer Decoder
Simulation

Required Eb/N0 for BER = 10^{-6}

- 16QAM
- QPSK
- GaN AB Amplifier
  - without pre-distortion
  - with pre-distortion
- linear channel

CCSDS 131.0 SCCC
Link margin of high-data-rate down
(2W GaN HEMT of AB class with pre-distortion)
Project Schedule

Onboard Tranmitter
‘13 June T EM test
‘13 June-Sep. FM manufacturing
‘13 Oct. FM test

Ground Antenna
‘13 March Installation

Ground Receiver
‘13 Aug. First test
‘13 Nov. Complete ?

Hodoyoshi - #4 (60kg) Launch
‘14 March by Dnepr

‘14 Demonstration 320Mbps 16QAM test on orbit

Now !

Goal !
Conclusions

1. Developing 320Mbps 16QAM down link for 50kg satellite.

2. Power-efficient transmitter
   (GaN HEMT amp with predistortion)
   small antenna (MGA, isoflux)

3. Small ground antenna,
   powerful receiver (turbo equalizer & decoding)

4. On-board demonstration in 2014 with 50kg sat.