300 Mbps Downlink Communications from 50kg Class Small Satellites

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1. Purpose: 320Mbps down link for small sat
2. Onboard segment: high efficiency 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 maunfacturing now.
Limits of Small Satellites for Earth Observations

• Mass Limit (<100kg), Power Limit (<100W)
  — Sensor 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.

Satellite Mass (kg) vs. Down Link Bit Rate (bps)
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.
## 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></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MGA</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</td>
<td>(348-144Mbps), 16QAM, QPSK</td>
<td>SCCC Turbo Equalizer CCSDS 131.2-B-1</td>
</tr>
</tbody>
</table>
High-Speed 16QAM Down Link with Nonlinear Amplifier

Input IQ Constellation  

Nonlinear Amplifier  

Output I-Q Constellation  

1 symbol transmits 4 bits  

AM & PM Distortion  

Inter Symbol Interference  

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

RF out

Small Distortion

Coordinate transformation
Rectangular to Polar

14bit

AM-AM LUT

AM-PM LUT

Coordinate transformation
Polar to Rectangular

14bit
# 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

GaAs (A)

GaAs (A)

GaAs (A)

AM/PM

IQ Constellation

Without Pre-distortion

GaN (AB)

GaN (F)

With Pre-distortion

Pre-distortion

⇒
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 showing EM Input-Output characteristics](image)

**EM Input-Phase shift characteristics**

![Graph showing EM Input-Phase shift characteristics](image)
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
16QAM I/Q Constellation @ 33dBm (PM RF+Digital)

Without Predistortion

*Obtained from the prototype model of transmitter without predistortion. RF output power = 33 dBm.*
Bit Error Rate v.s. Eb/No

EM RF Block, uncoded 16QAM

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

Body-Fixed Medium Gain Antenna

14 dBi, 68g

14 dBi, 68g, 7x7cm

3.8m Ground Station

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

S-band Corrugated Horn
X-band Dielectric Rod

Sub-reflector
Secondary Focus (System Focus)
Primary Focus (Ring Focus)
Block diagram of high-data-rate downlink and ground receiver

Transmitter

- Packet generator
- SRRC filter
- Pre-distortion
- Power amplifier
- RF BPF

Receiver

- Complex NCO
- Loop filter
- Phase detector

Frequency tracking loop (FTL)

- Signal resampler
- Matched filter

Timing tracking loop (TTL)

- Signal searcher
- Loop filter
- Timing detector

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

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

- GaN AB Amplifier without pre-distortion
- 16QAM
- QPSK

 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 Transmitter
- ’13 June T EM test
- ’13 June-Sep. FM manufacturing
- ’13 Oct. PM test
- ’13 Nov. FM test

Ground Antenna
- ’13 March Installation

Ground Receiver
- ’13 Nov.-Dec. Front-End install
- ’14 Feb. Complete (collimation test)

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.
Advanced Mission - 100kg SAR Satellite -

- Deployable, Rectangular, Slot Array Antenna with Waveguide Feeder
- Compact stow volume 0.7x0.7x0.7m
- Front panel: SAR antenna
- Rear panel: Flexible Solar Cell
Deployable Slot Array Antenna

(a) Backside and Waveguide Feeder
(b) Slot Array Antenna Panel
(Feeder is removed)