

# **300 Mbps Downlink Communications from 50kg Class Small Satellites**

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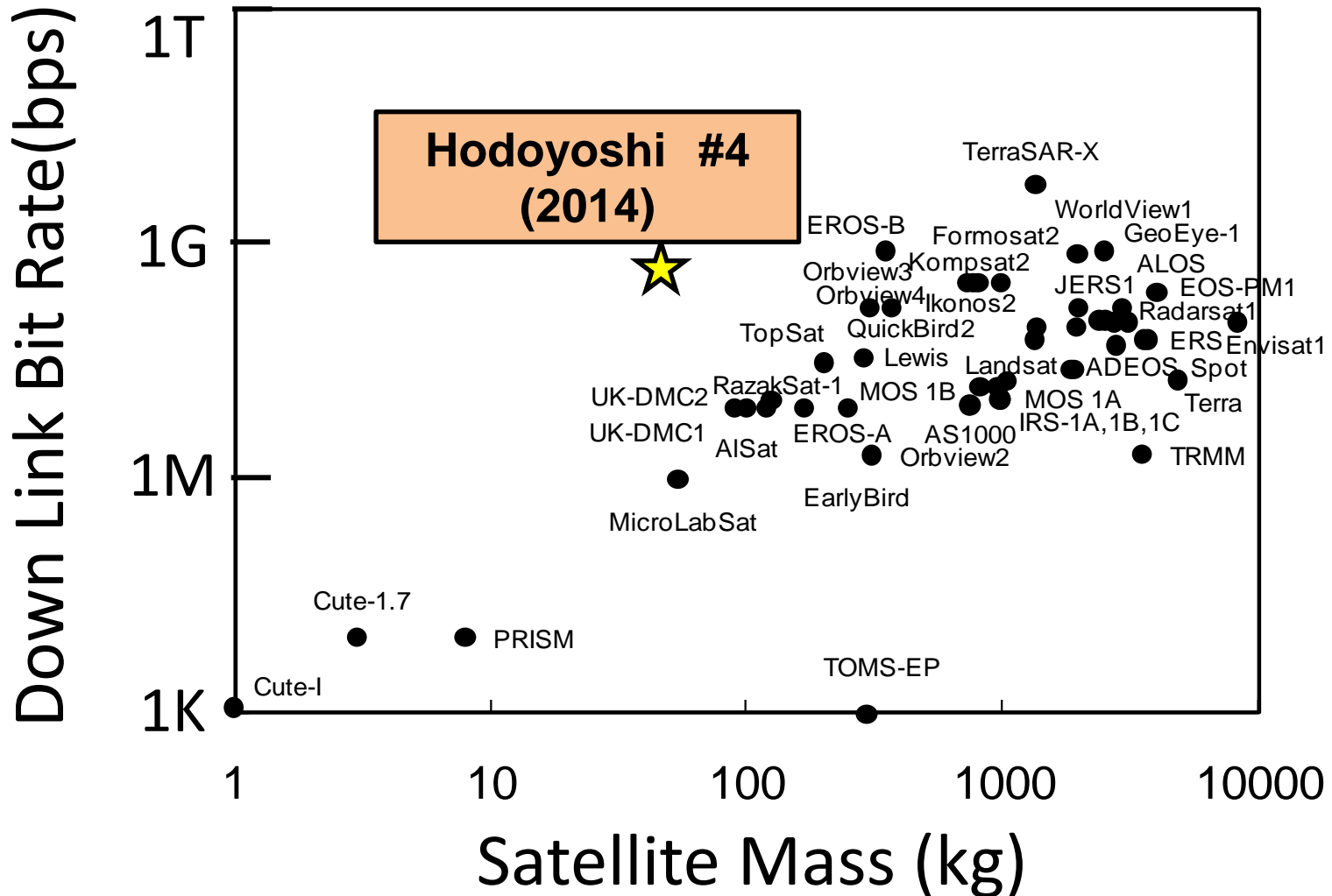
# Contents

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 manufacturing now.
6. On-orbit demonstration : 2014 with 50kg sat.

# 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.



# High Speed Down Link for Small Sat

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

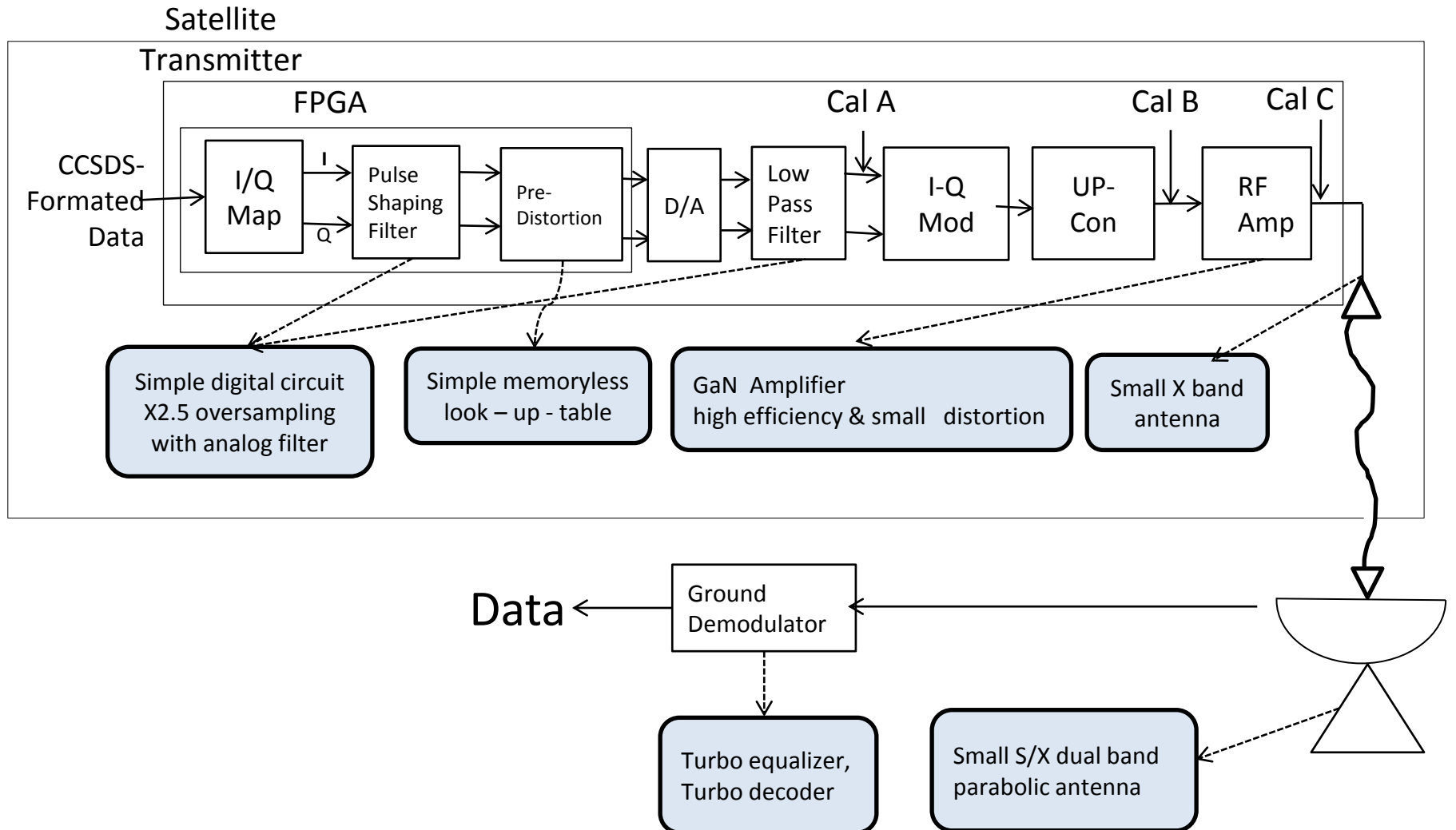
—Goal

50kg Sat @600km orbit

DC power <20W, 320Mbps

Small Ground Antenna < 4m

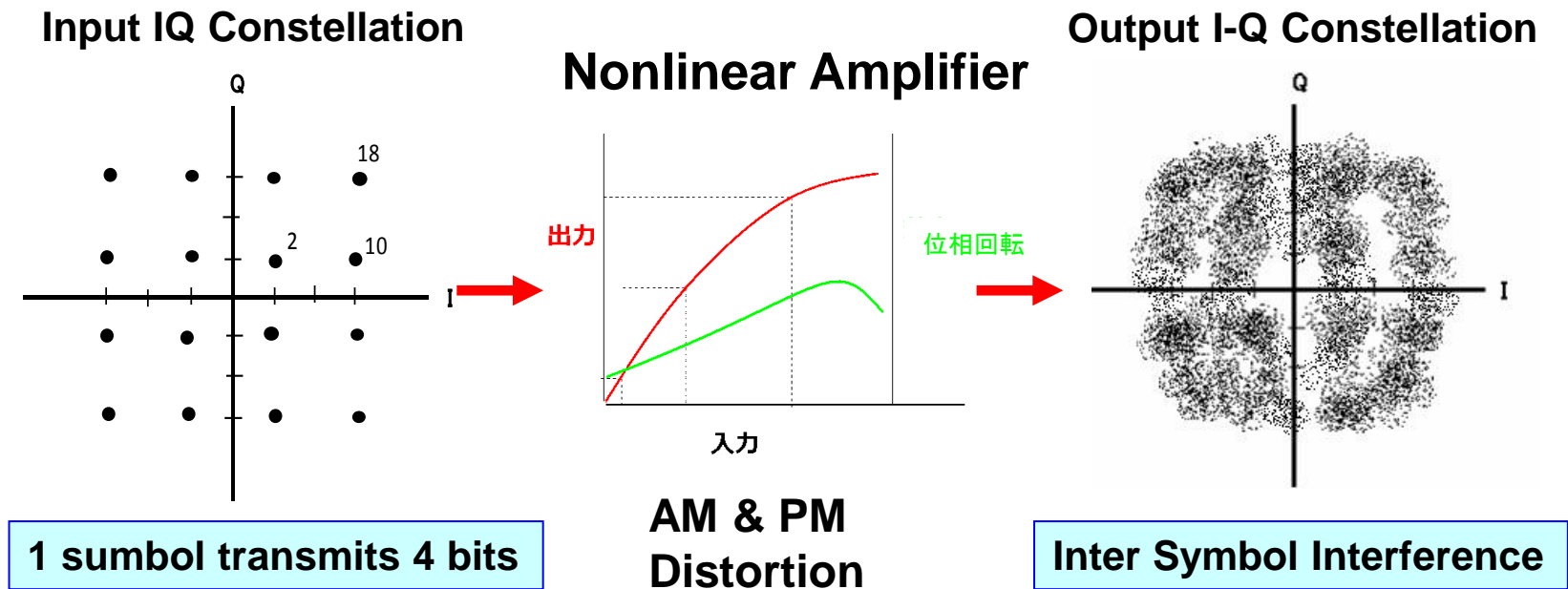
# System block diagram of high-data-rate downlink.



# Performance of High - Data - Rate Down Link

| Instruments    | Mass (g)  | Power (W) | Remarks                          |
|----------------|---|-----------|----------------------------------|
| On-board       |   |           |                                  |
| Transmitter    | 1330  | 18        | 16QAM, 348Mbps<br>GaN Power Amp. |
| Antenna        |   |           |                                  |
| MGA            | 69  | 0         | 13.5 dBi                         |
| Iso-flux       | 150   | 0         | 5dBi(60°) , -2dBi(0°)            |
| Ground Station |   |           |                                  |
| Antenna        | 3.8m Dia. S/X Cassegrain, 47.5dBi(X), 36dBi(S), Sys. Noise temp. 100K       |           |                                  |
| Demodulator    | 100Msps, (348-144Mbps), 16QAM, QPSK<br>SCCC Turbo Equalizer CCSDS 131.2-B-1 |           |                                  |

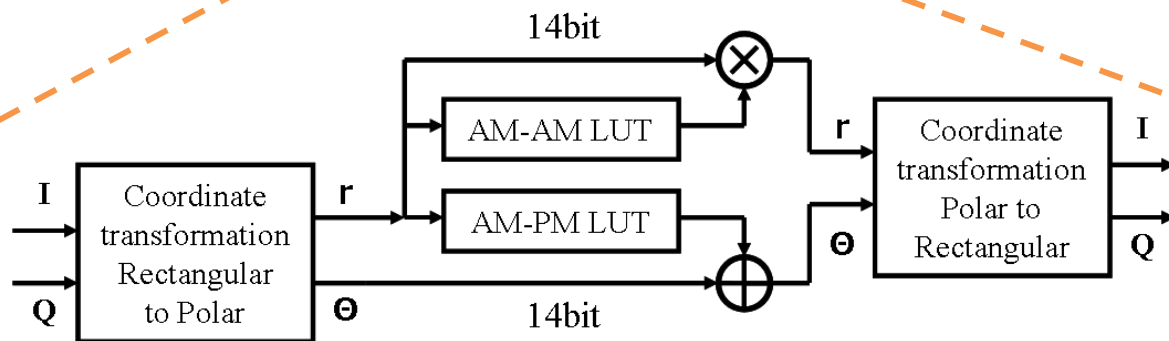
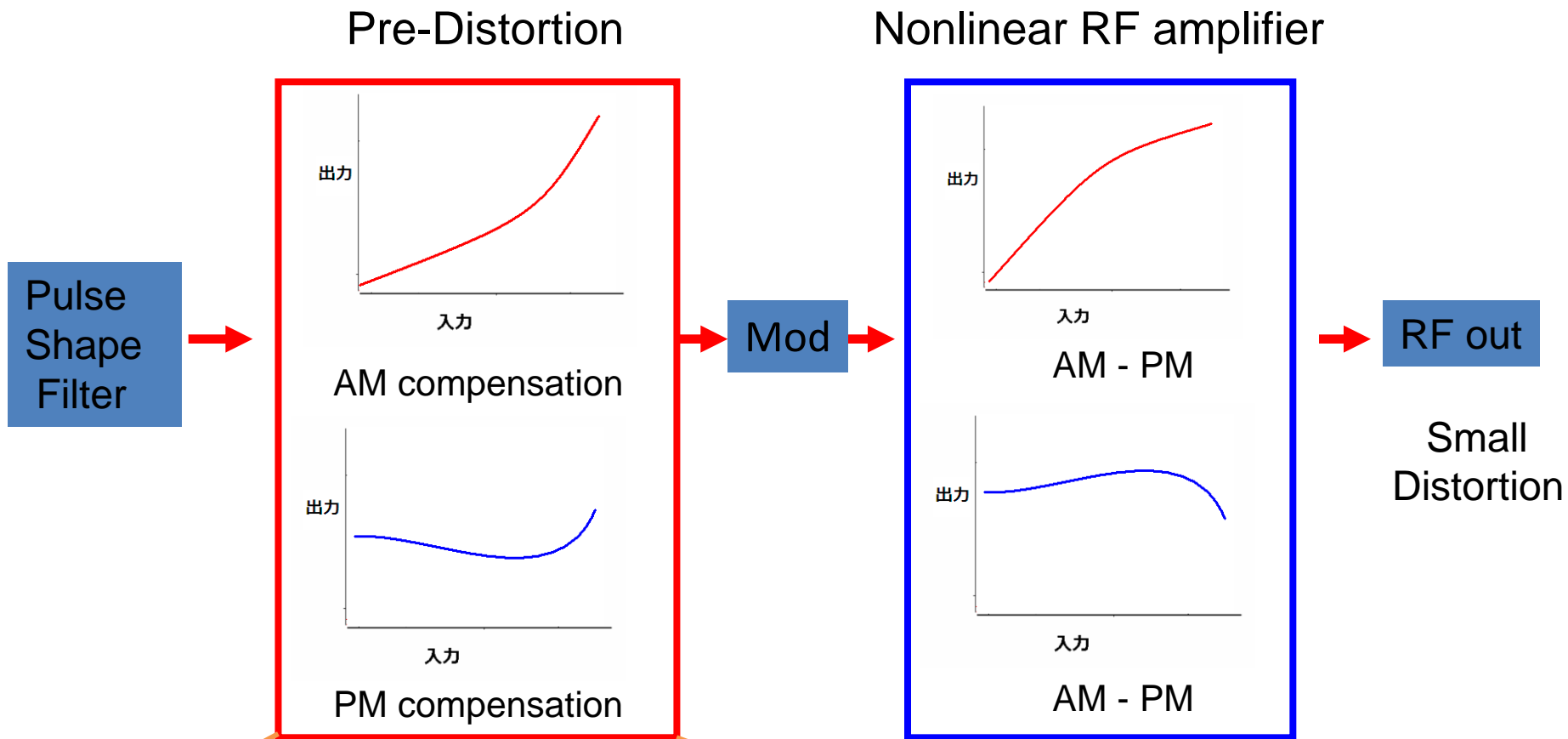
# High-Speed 16QAM Down Link with Nonlinear Amplifier



**High efficiency RF amplifier may degrade bit error rate**



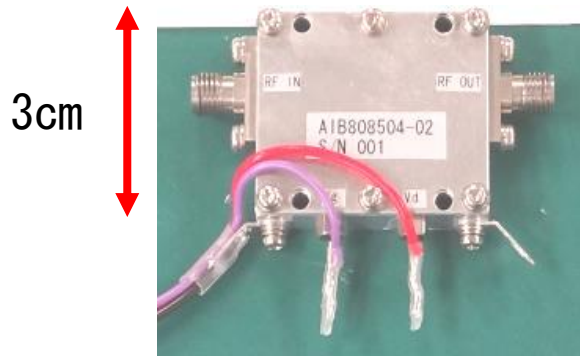
# Digital Pre-distortion compensates Nonlinearity



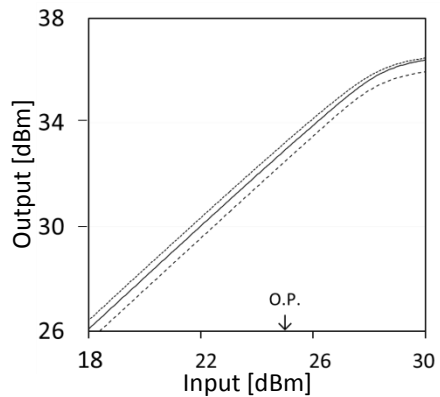
# X Band Power Amplifiers

| Amplifier           | GaAs AB | GaN AB | GaN F |
|---------------------|---------|--------|-------|
| Maximum Power       | 38dBm   | 37dBm  | 36dBm |
| Maximum Gain        | 10dB    | 11dB   | 12dB  |
| Maximum PAE         | 37%     | 46%    | 60%   |
| PAE at 3dB OBO      | 23%     | 36%    | 38%   |
| Maximum Phase Shift | 10°     | -2°    | -34°  |

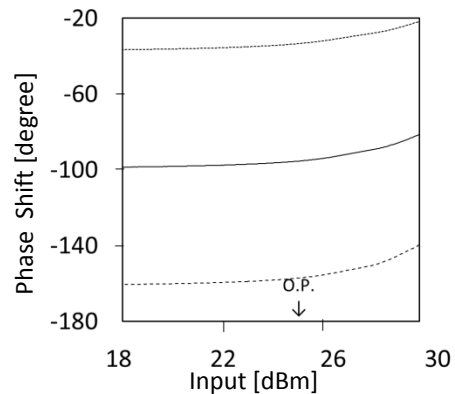
Newly Developed 2W **GaN HEMT AB Class**



AM/AM

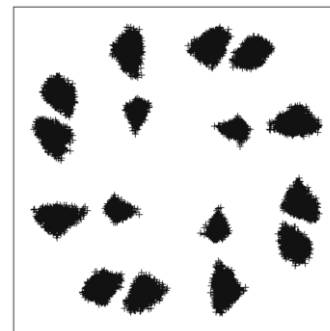


AM/PM



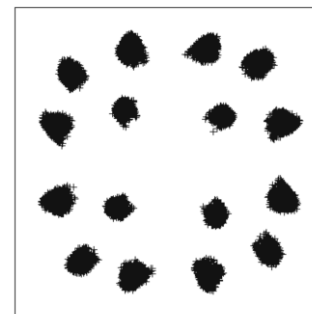
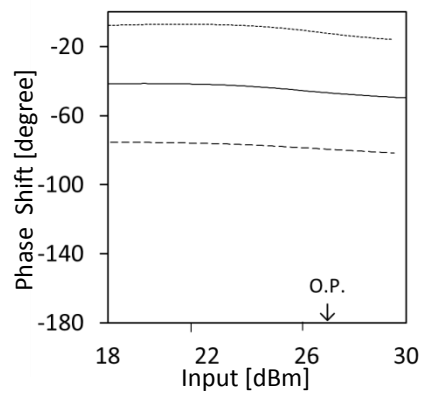
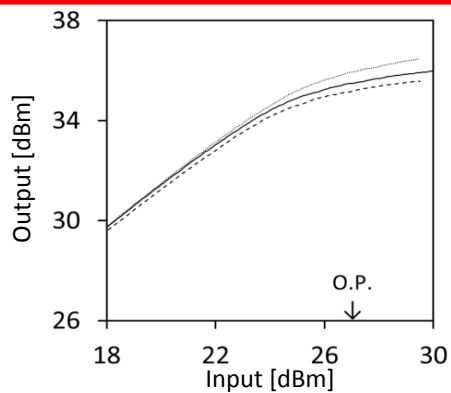
IQ Constellation

Without  
Pre-distortion

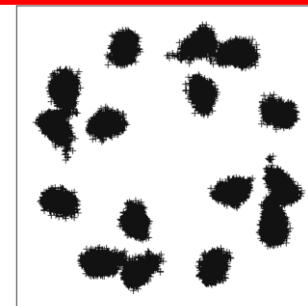
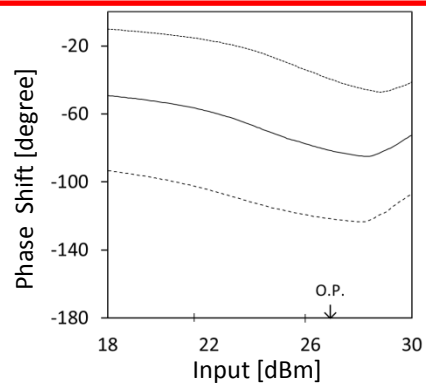
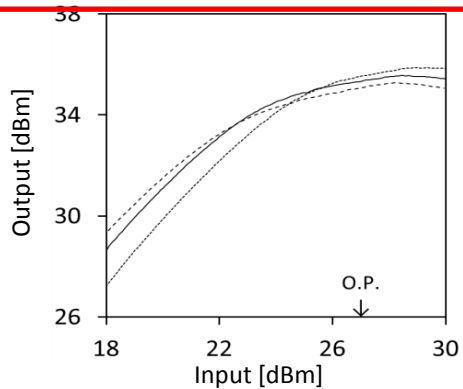


GaAs  
(AB)

GaN  
(AB)



GaN  
(F)



AM/AM

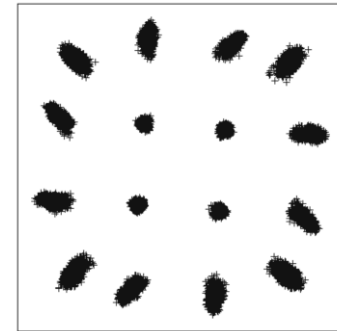
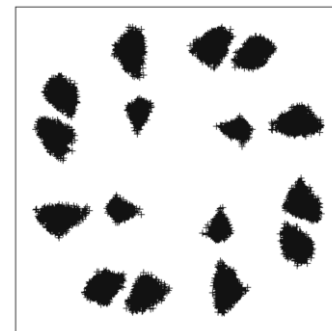
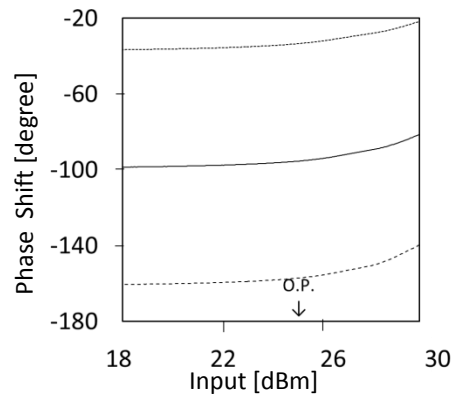
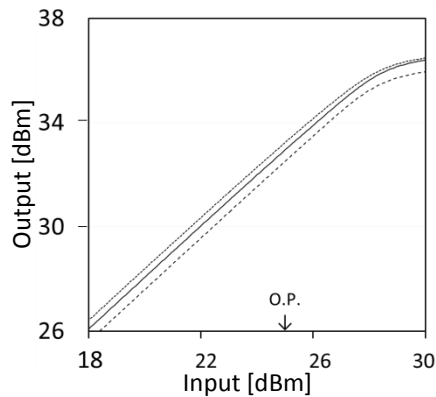
AM/PM

IQ Constellation

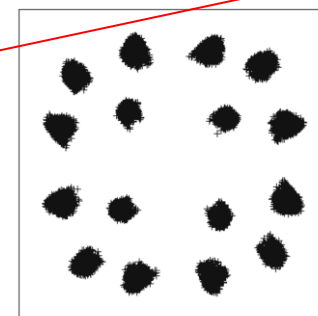
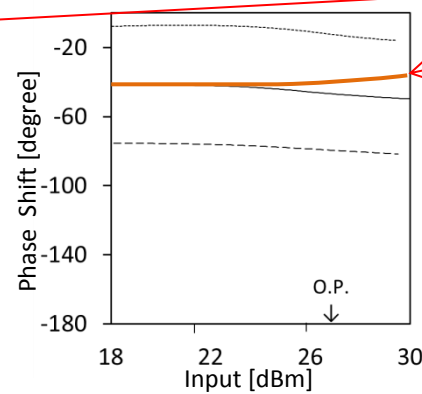
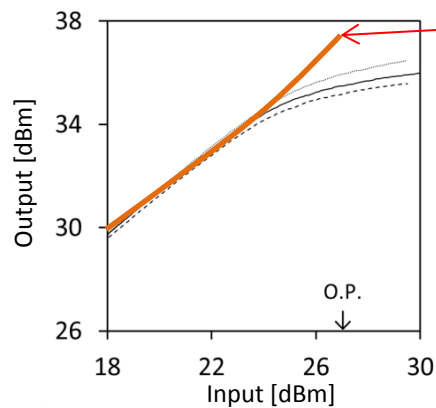
Without  
Pre-distortion

With  
Pre-distortion

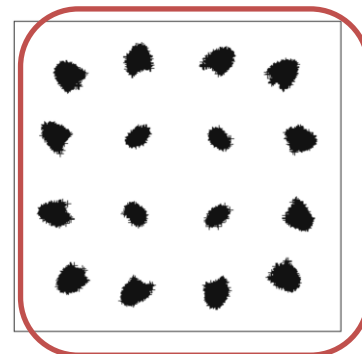
GaAs  
(A)



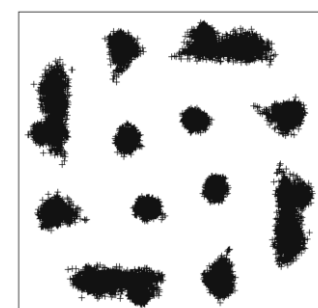
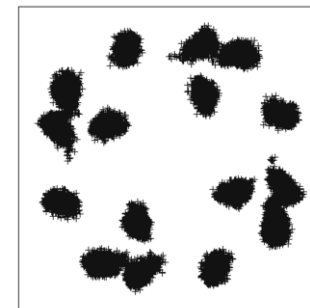
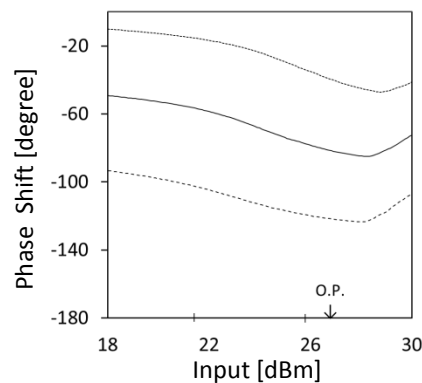
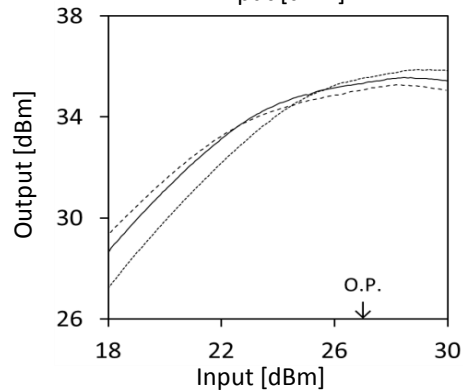
GaN  
(AB)



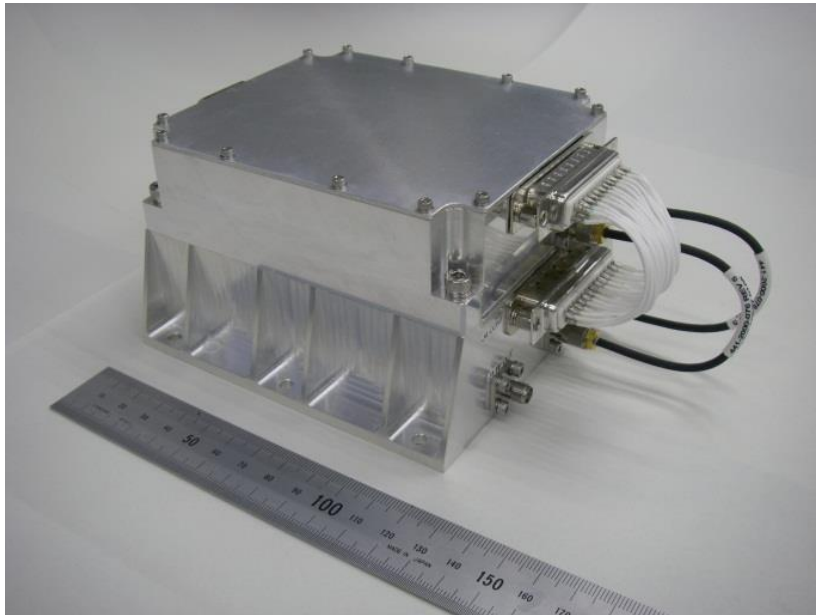
Pre-distortion



GaN  
(F)



# EM of 348 Mbps Transmitter



Modulation:16QAM/QPSK

Mass : 1330g

RF Power: 2W

DC Power :20W

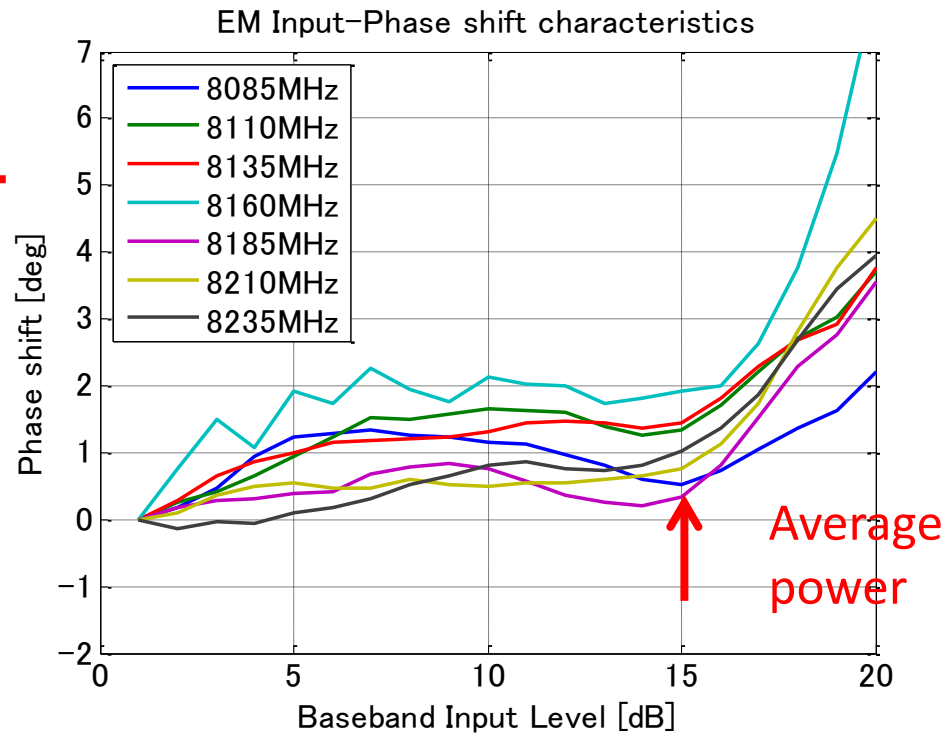
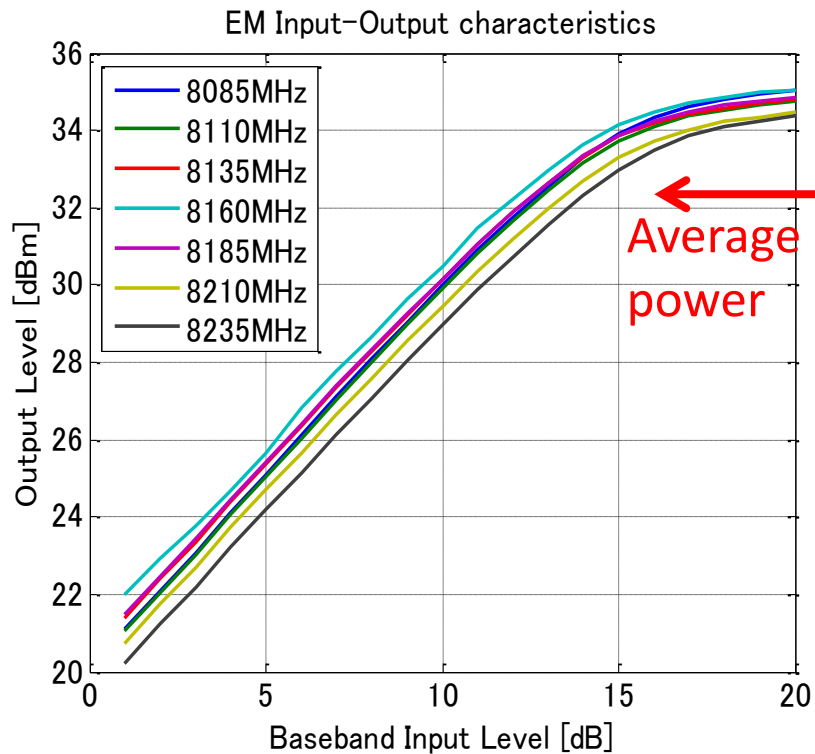
# AM-AM, AM-PM Characteristics

## X-band Transmitter (EM)

Efficiency(PAE) 47% (PA, GaN-HEMT)

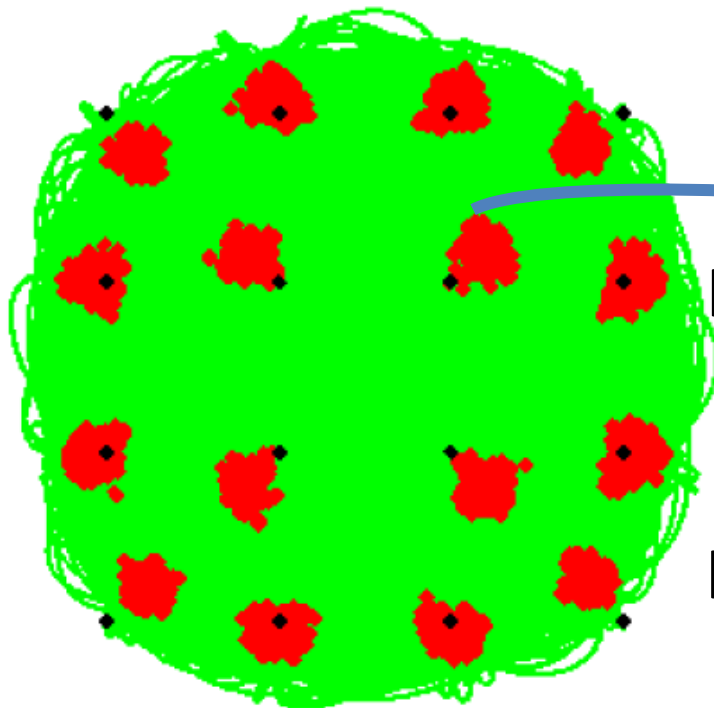
Output Backoff 2dB

Phase Shift 2 deg (average)



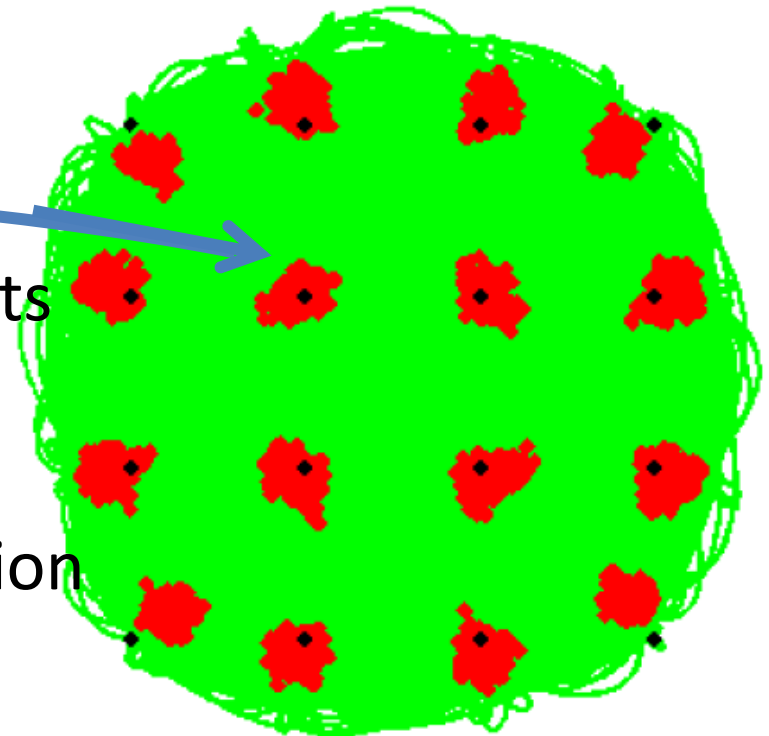
# 16QAM I/Q Constellation @ 33dBm (EM RF block)

Without Predistortion



(a) Without pre-distortion

With Predistortion



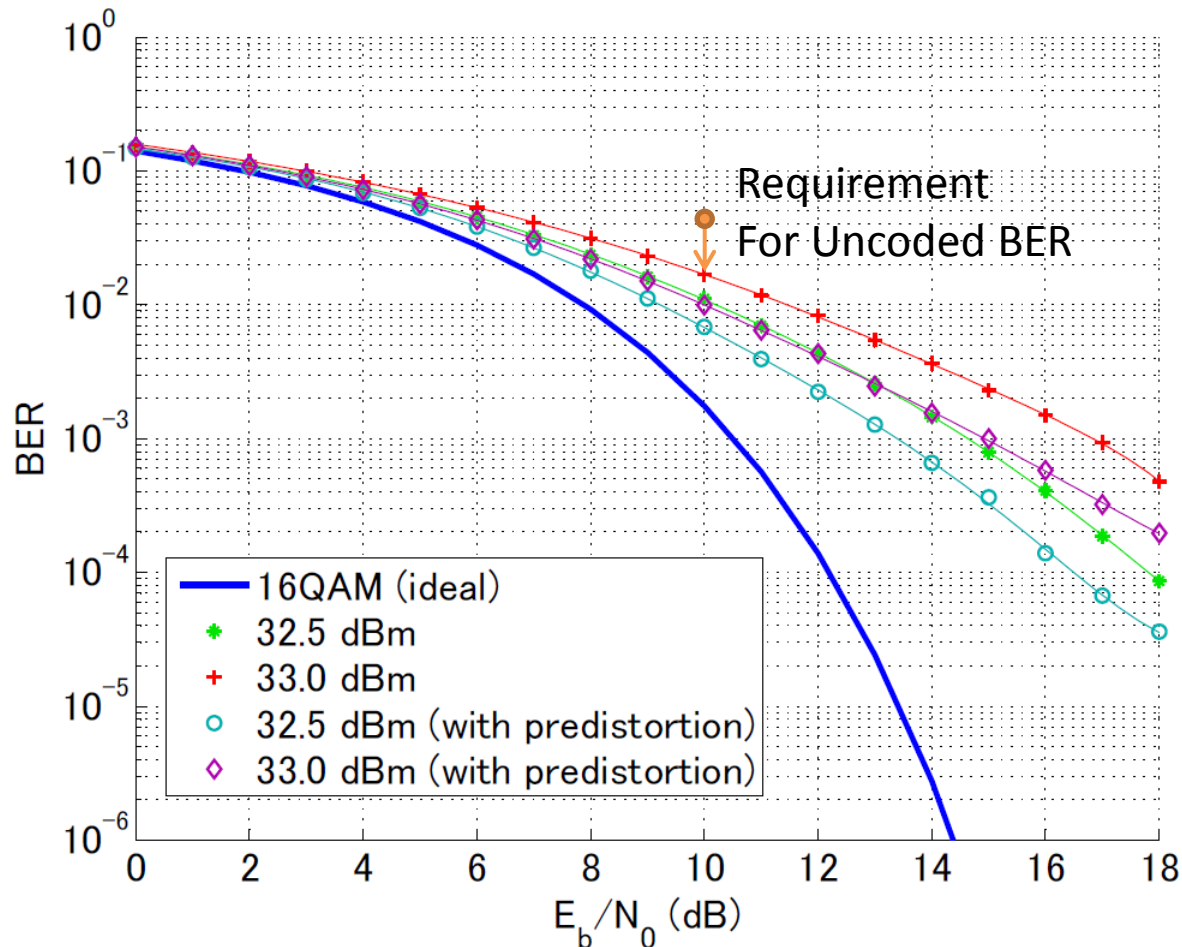
(b) With pre-distortion

Inner Points  
Improved  
By  
predistortion

# Bit Error Rate v.s. $E_b/N_0$

## EM RF Block, uncoded 16QAM

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



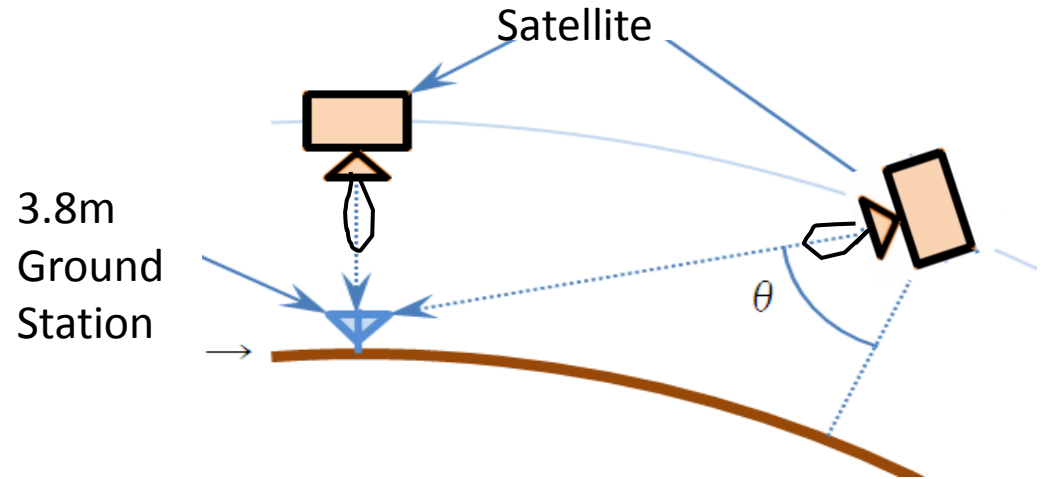
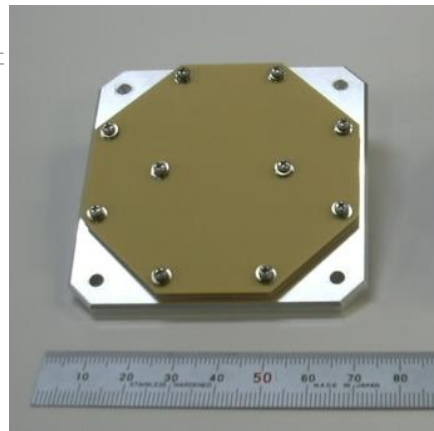
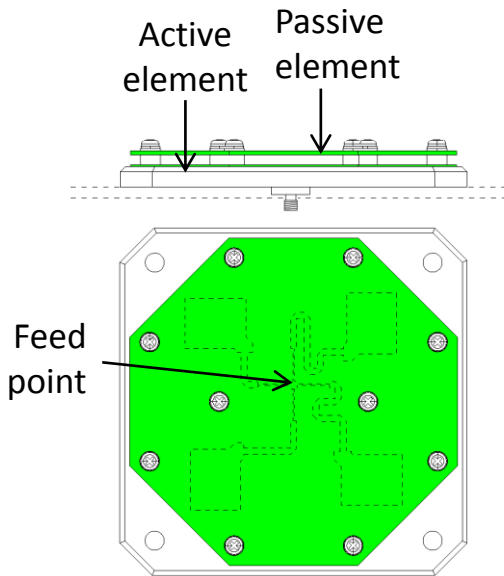


# Onboard Small Antenna

## Body-Fixed Medium Gain Antenna

14 dBi, 68g

14 dBi, 68g, 7x7cm



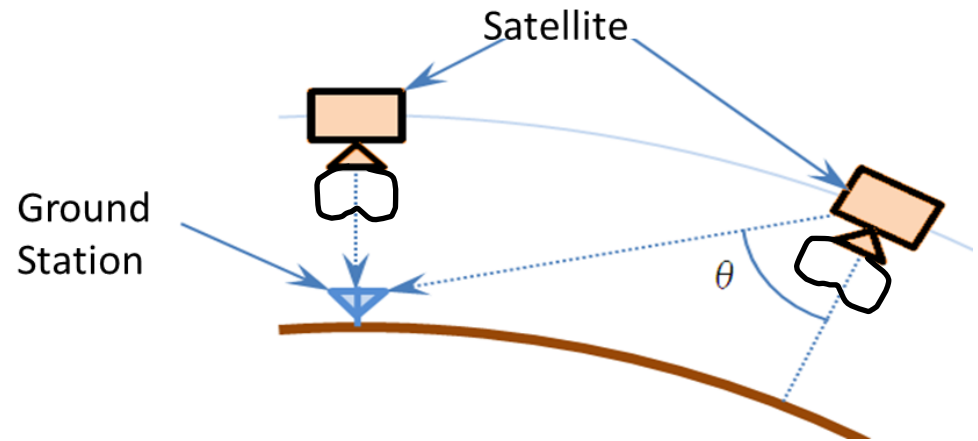
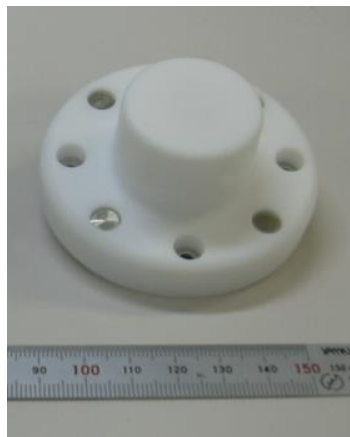
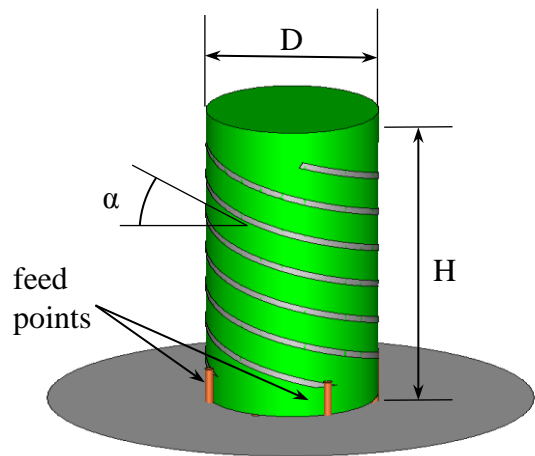
For **320Mbps** high bit rate mode,  
Satellite points earth station

# Onboard Small Antenna

## Body-Fixed Iso-flux Antenna

5dBi max, 150g

quadrafilar helix  
150g, D=10mm, H=20mm



For Earth-Pointing Satellite,  
Antenna pattern compensates  
range variation

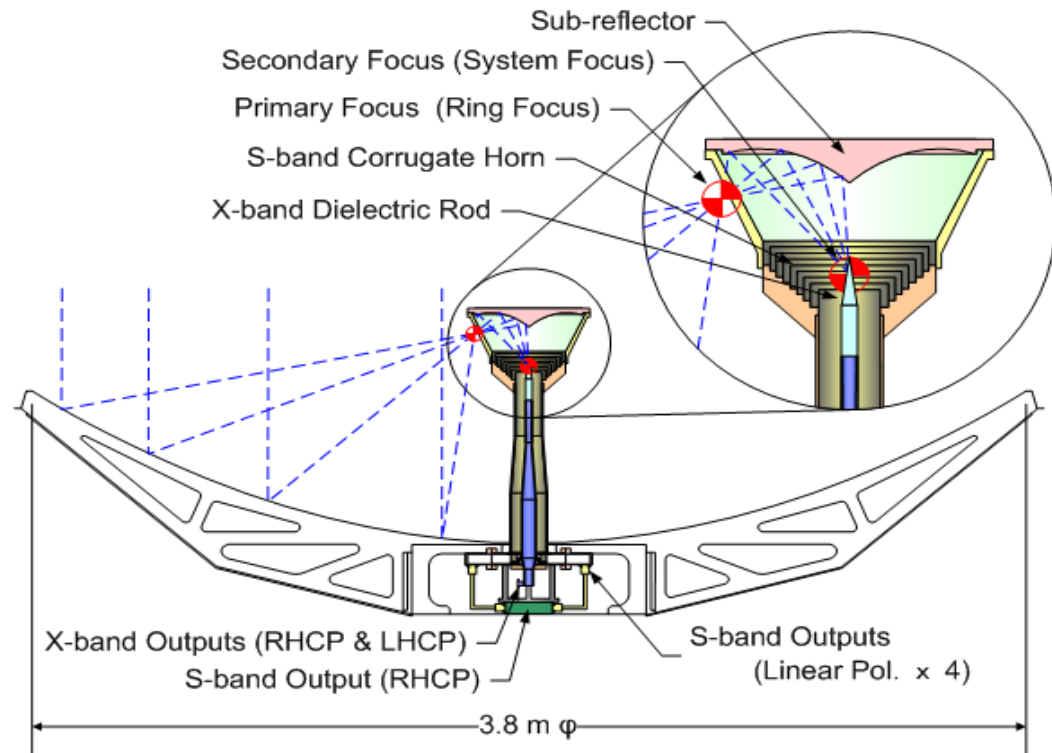
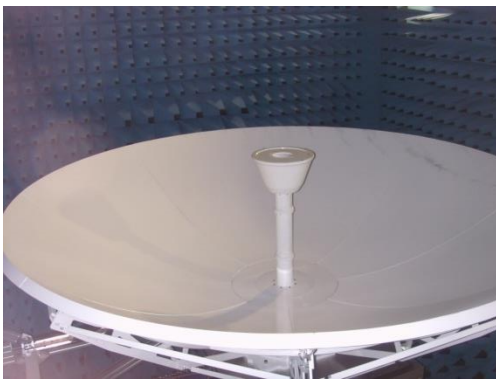
# Ground Antenna

## 3.8m Ground Antenna for S / X Band

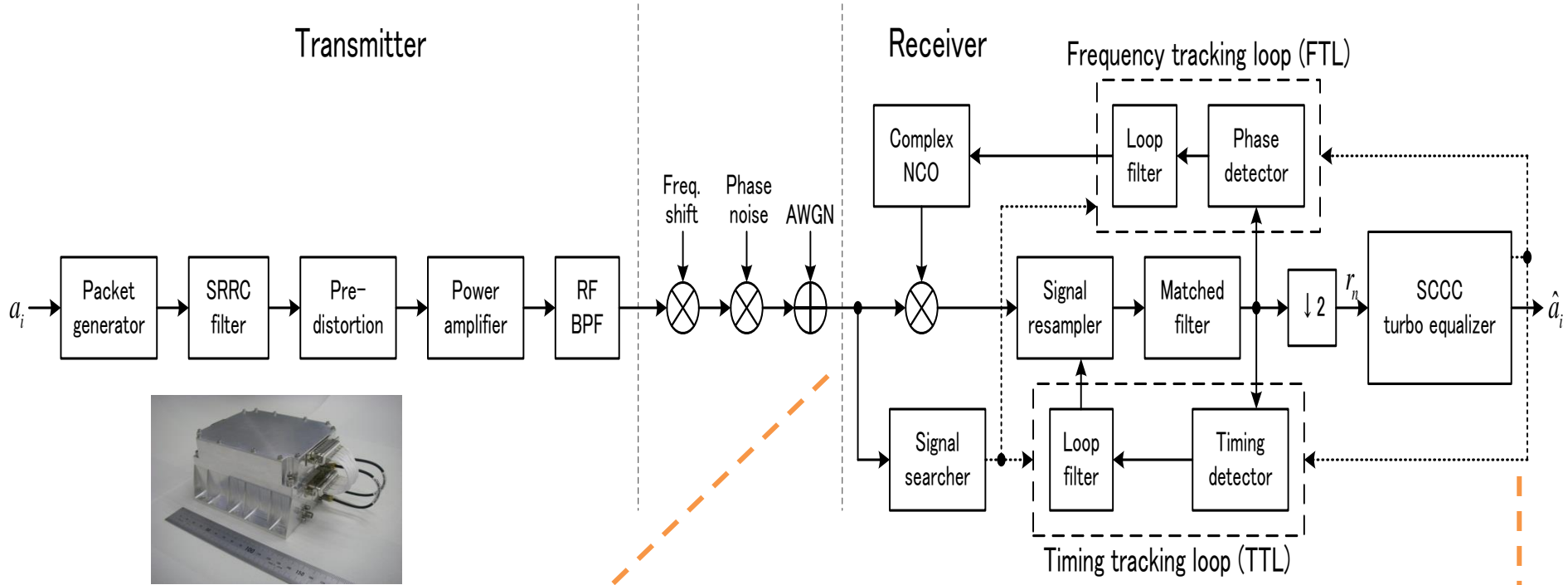
S band : Telemetry & Command

X band : Mission Data Down Link (320Mbps)

Ring-Focus  
Cassegrain



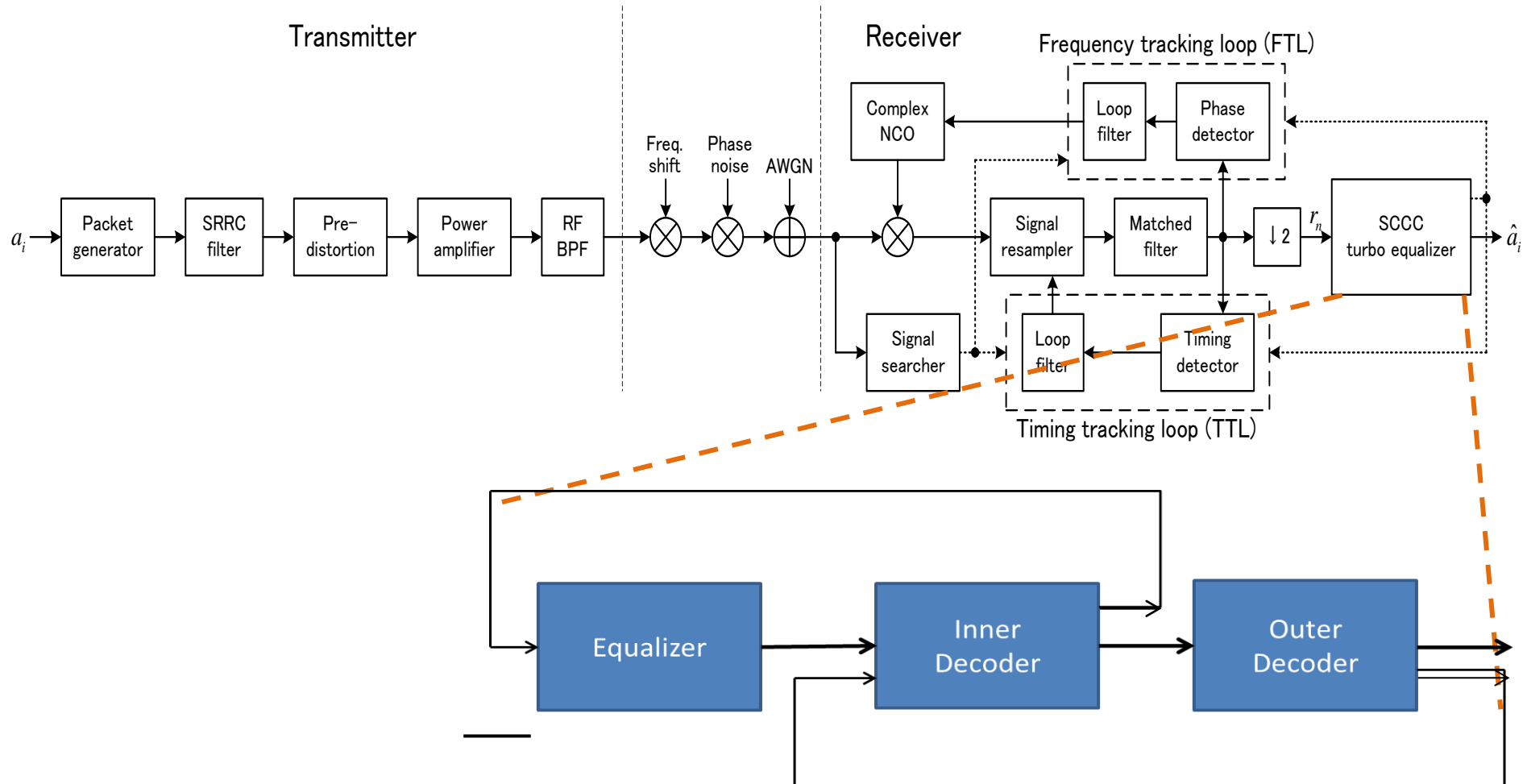
# Block diagram of high-data-rate downlink and ground receiver



Developing 400Mbps  
16QAM ground receiver

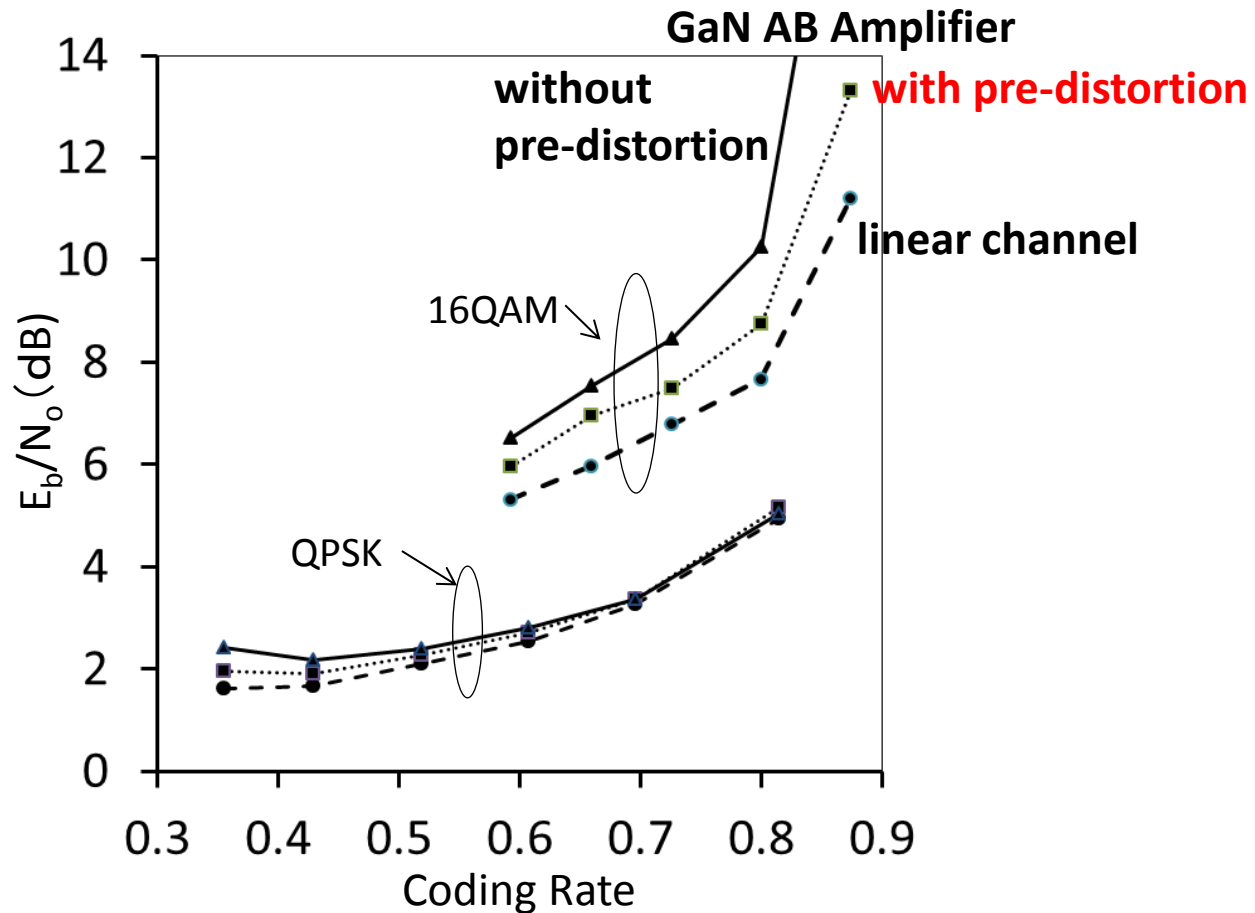


# Block diagram of high-data-rate downlink and ground receiver



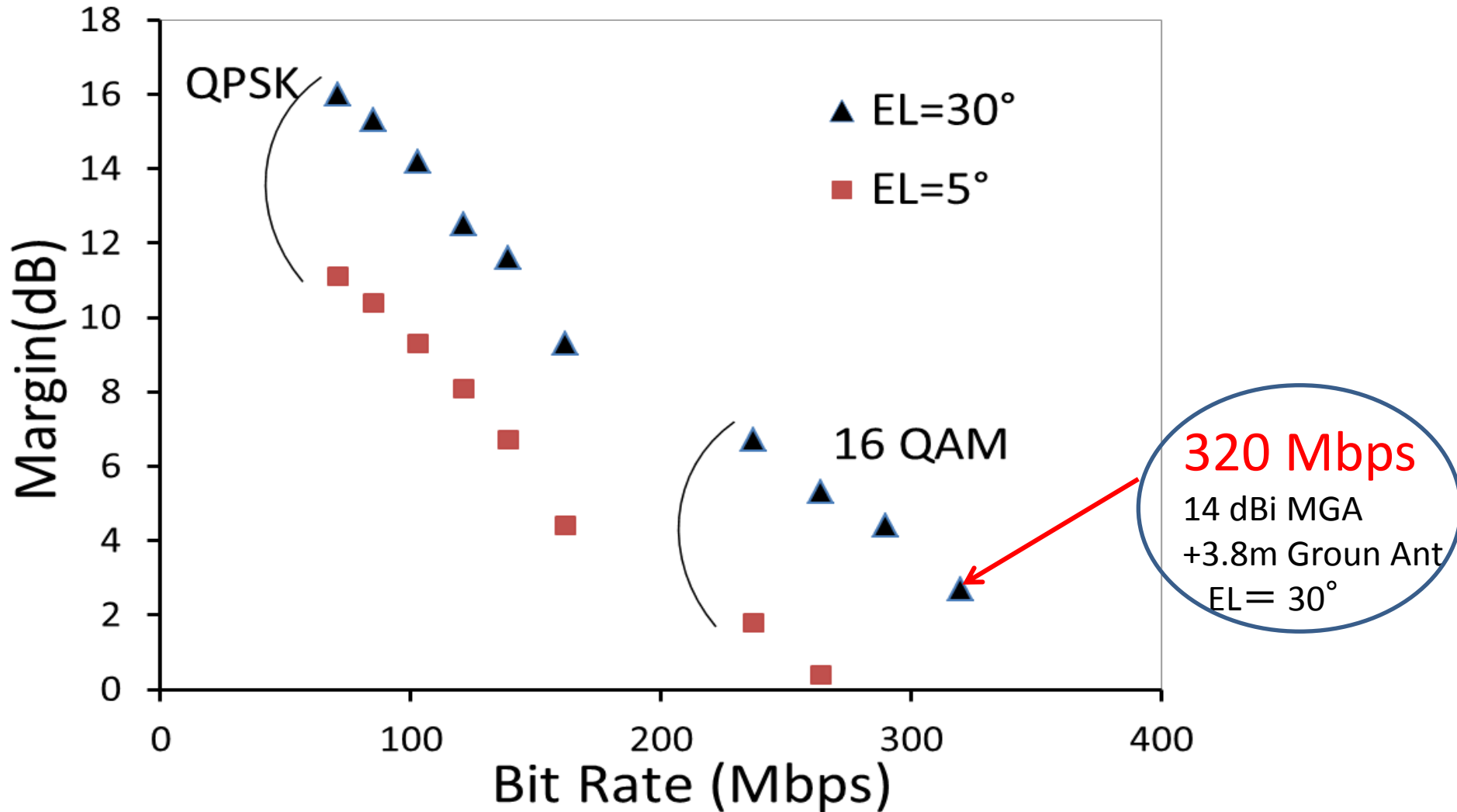
# Simulation

## Required $E_b/N_0$ for BER = $10^{-6}$



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

Now !



'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

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.**