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TOKYO DENKI UNIVERSITY

Institute of Space and Astronautical Science

火星探査無人航空機用高度計の開発

Experiment of a Radar Altimeter for an UAV Cruising in the Mars' Atmosphere

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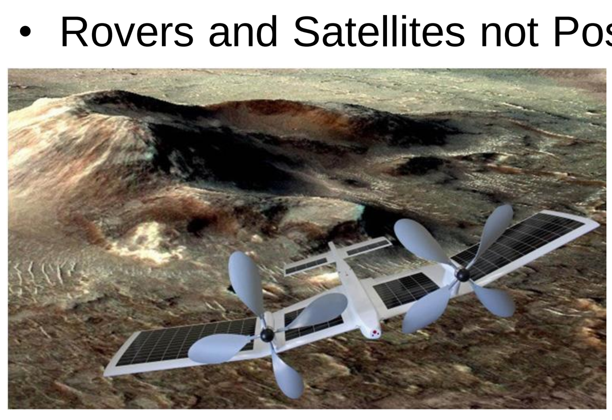
Mars Exploration — Airplanes

- JAXA
  - ➢Light Airplane Observations
    - ➢Magnetic Fields
    - ➢Exposed Strata
- Rovers and Satellites not Possible



- 4.2 kg
- 2.6 m wingspan
- Stored in a capsules
- Ejected from satellite

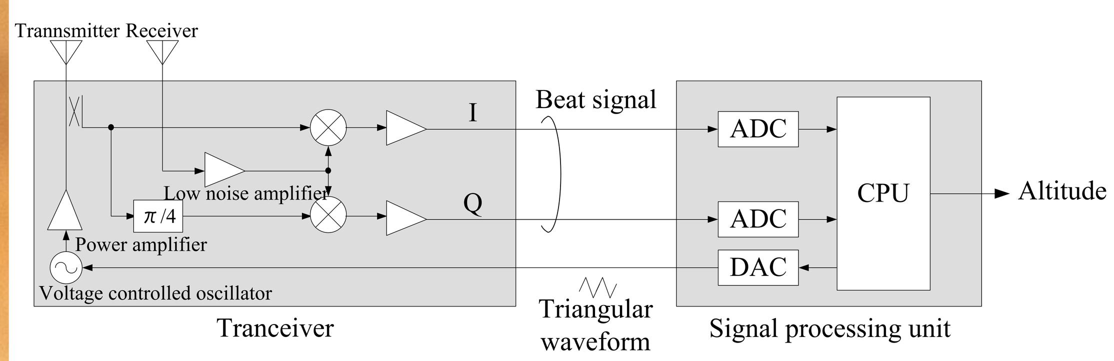
Requirements for an Onboard Altimeter

Tentative Specifications

Weight	100 to 200 g
Power consumption	< 1 W
Measurable altitude	0.2 to 10 km
Observation altitude	1 to 3 km
Altitude resolution	< 10 m during observation < 100 m otherwise
Refresh rate	1 time / second

Block Diagram

- FM-CW radar vs. Pulse radar
  ↑
  - ➢Signal processing — easier
  - ➢Less power-consuming
- Ka band



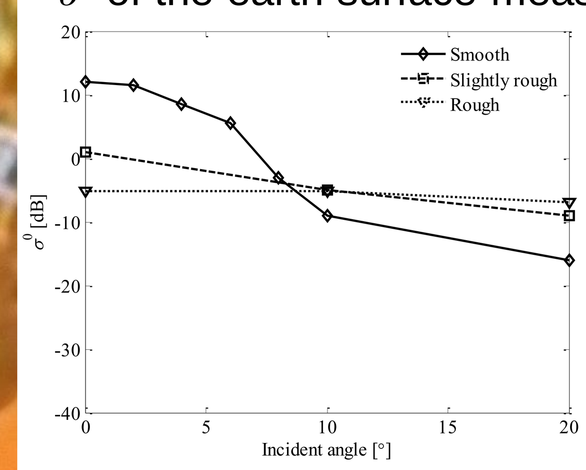
Link Budget Estimation (1/4)

Signal to Noise Ratio $= \dfrac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 R^4 L_s k T B F_n}$ (1)

where
- P_t: Transmitting power
- G: Antenna gain
- σ: Radar cross section = σ^0 ×illuminating area $= \sigma^0 \cdot \frac{\pi R^2}{1.33^2} \tan^2\left(\frac{\Phi}{2}\right)$
  - σ^0: Normalized radar cross section
  - Φ: Half-power beamwidth of the antenna
- λ: Wavelength
- R: Altitude
- L_s: Feeder loss
- k: The Boltzmann constant
- T: Temperature
- B: Bandwidth
- F_n: Noise figure

Link Budget Estimation (2/4)

σ^0 of the earth surface measured at Ka band

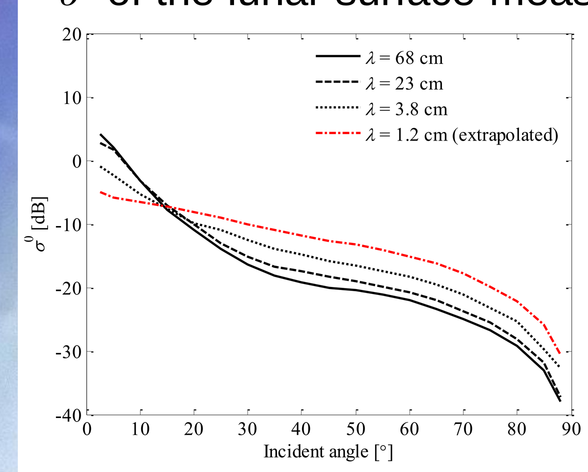


- Rougher surface results in less dependence on the incident angle.

T. Tagawa, K. Okamoto, A. Higuchi, T. Ushio and T. Oguchi, "Measurement of Scattering Coefficients of Soil by Ka-Band Polarimetric Scatterometer—Dependence on Soil Moisture Content and Surface Roughness—," Trans.Inst. Electron. Inform. Communi. Engnr. Jpn.(B), vol.J89-B, no.2 pp.286-295, Feb.2006.

Link Budget Estimation (3/4)

σ^0 of the lunar surface measured at UHF, C and X band



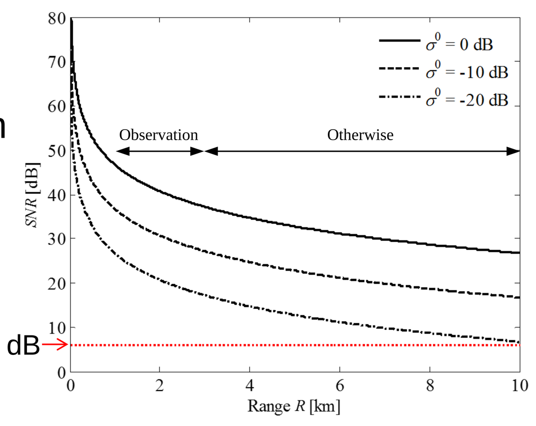
- Higher frequency results in less dependence on the incident angle.

S. Fukuda, T. Mizuno, T. Sakai, H. Tomita and H. Ishimaru, "Development of the C-Band Pulse Radar for Lunar / Planetary Landers, "Technical Report of IEICE, SANE, vol.104 No.469, pp.7-12, Nov.2004.

B. A. Campbell, Radar Remote Sensing of Planetary Surface, Cambridge Univ. Press, Cambridge, 2002.

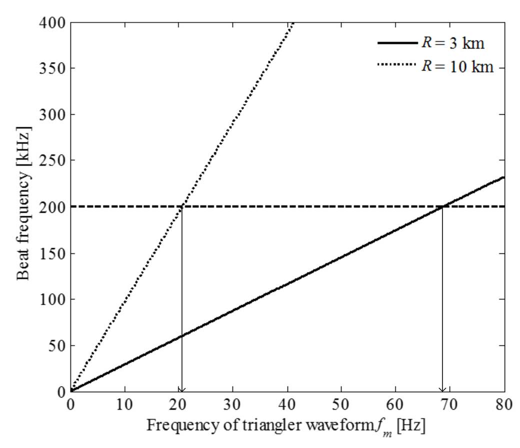
Link Budget Estimation (4/4)

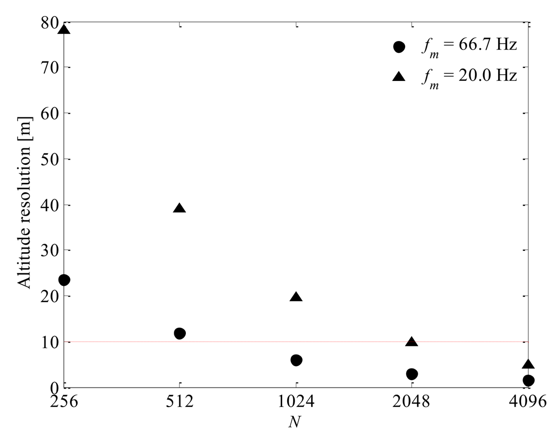
- σ^0 of the mars' surface — Unknown
  - ➢Estimated : -20 to 0 dB
- Assumptions:
  - Transmitting power: 23 dBm
  - Antenna gain: 32 dBi
  - Noise figure: 6 dB
- SNR > 6 dB is required



- The altitude can be measured when σ^0 = -20 dB and R = 10 km (the worst condition).

Resolution examination

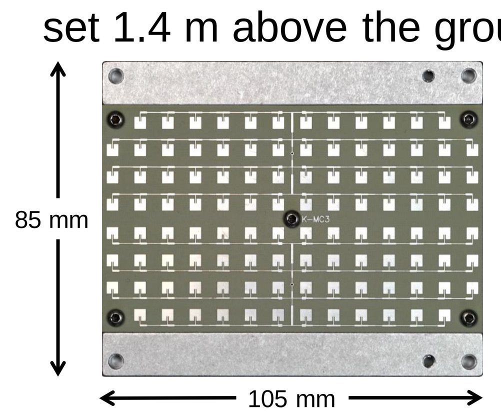




- To measure an altitude of 3 or 10 km, the f_m should be less than 20.0 or 66.7 Hz when the f_s = 400 kS/s.
- $N \geq 1024$ was needed to achieve a resolution of 10 m during the observation.

Measurement setup

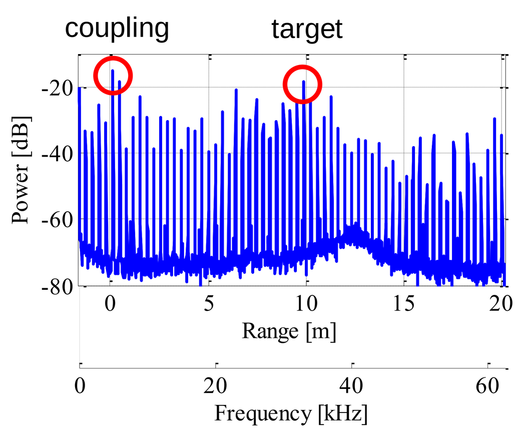
- Target
  - ➢A vertical concrete wall of a building
- The measurement range was 5 to 24 m.
- The transmitting and receiving antennas were set 1.4 m above the ground.

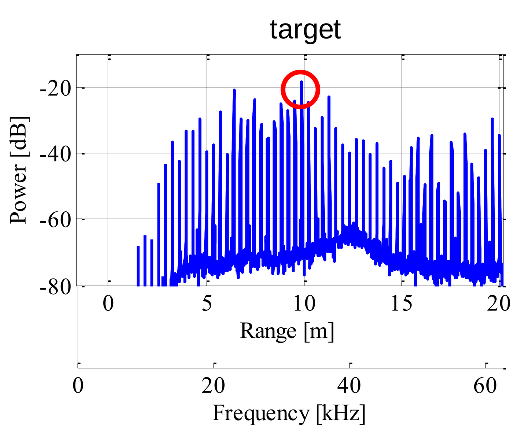


- 24.15 GHz
- 54-element microstrip arrays
- Including a transceiver

RFBeam KMC-3

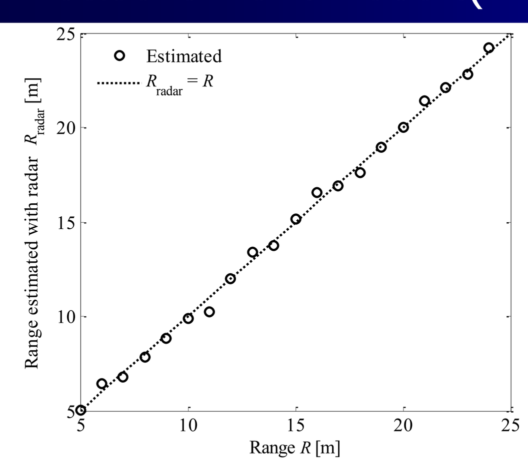
Measurement Result(1/2)

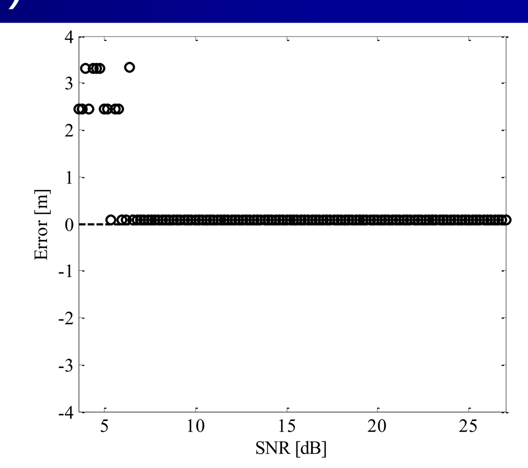




- This figure included coupling between the transmitting and receiving antennas
- A high-pass filter was applied.
- The resulting spectrum exhibited a correct ranging at R = 10 m.

Measurement Result(2/2)





- Standard deviation was 0.31 m.
- Good agreement was observed between the real range and that estimated with the radar.
- Estimation error appeared when SNR < 6 dB

Summary

- Feasibility of the altimeter was examined within limits of weight and power consumption through the adoption of a FM-CW radar technology.
- Link budget estimation revealed that the altitude can be reliably measured under the severest conditions at an altitude of 10 km.
- Preliminary experimental evaluation was carried out and, good agreement was observed between the real range and that estimated with the radar.
- An unmanned helicopter experiment will be carried out to extend the range.

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