FMCW Radars for Planetary Landers: Lessons Learned from the Huygens Radar Altimeter

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Overview

Presentation Overview

- FMCW Radars – Principle
- The Huygens Altimeter: Design, Interfaces, Signal Processing
- Altimetry and Surface Backscatter Measurements
- Surface Topography and Spectral Data
- Atmospheric Backscatter Measurements
- Design and Performance Improvements
- Radar Operations: Altimetry and Science
- Conclusion
FMCW principle

- constant power output
- frequency modulated by triangular waveform
- received frequency mixed with transmitted freq
- difference freq is kept constant at defined IF frequency

=> triangular signal frequency prop to 1/ Alt

Applications

- altimeters
- cloud radars

=> simple to implement
=> light and reliable
Huygens HRA: Design

HRA design features

- Probe system, not payload
- Fully redundant system
- Tx frequencies 15.4 GHz, 15.8 GHz
- Output power ~ 100 mW
- FM bandwidth 30 MHz
- Input to Mixer Noise temp ~ 263 K
- 15 kHz IF BW, 200 kHz IF freq
- 50 dB AGC gain range
- Design alt range 10 km (initial), up to ~ 60 km (after modifications)

Data products

ALT data (digital interfaces), AGC data (analogue HK), IF data (PWA science)

Scientific utilization was result of Huygens PS initiative, GR issues etc. - late implementation
Huygens HRA: Interfaces & data processing

HRA

RAE

HASI-PWA

CDMU

HK data

PWA data

IF spectra

PWA alt

AGC data

ALT data

Blk signal

210kHz Band Pass

15kHz

10kHz

Digital Signal 48kHz

FFT and summation

A/D

IPPW-3 5
Altimetry and Surface Backscatter

FMCW ramp rate → Altitude → Backscatter coefficient
IF spectral power
AGC voltage → RX power
TX power

RADAR Altitude Data  File: RA-C-ORD.MAT

Time [sec]  Altitude [km]
1000  2000  3000  4000  5000  6000  7000  8000  9000
10  20  30  40  50  60

IF band power [dBV^2]
1000  2000  3000  4000
-20  -10  0  10  20  30

AGC voltage [V]  Altitude [km]
1.5  2  2.5  3  3.5
0  5  10  15  20  25  30

IF band power [dBV^2]
1.5  2  2.5  3  3.5
0  5  10  15  20  25  30
Surface topography and spectral data (1)

- Antenna pattern
- Off-nadir (attitude)
- HRA
- RAE
- PWA

Small scale roughness (e.g. Geometrical Optics)
RMS height / correlation length

Large scale roughness (facets)
Local incidence angle

Power [dBV]
Freq [2.5 – 17.5 kHz]
Surface topography and spectral data (2)

Huygens data
Atmospheric backscatter measurements (1)

**Emission and backscatter**

- **Pt**: transmitted power
- **Sp**: prop. $1/D^2$
- **Sr**: prop. $1/D^4$ for 1 particle
- **V**: prop. $D^3$

$\Rightarrow$ **Sr** prop. $1/D$, **Pr** prop $1/D$

for backscattered signal

**Important factors:**

- Transmitted power
- **Z** – factor (total backscatter cross-section)
- Receiver chain noise level and interference
Atmospheric backscatter measurements (2)

Aerosol backscatter

- 1/D signal visible: Z parameter and aerosol properties can be derived
- 1/D not visible: upper limits for Z can be derived

Huygens data:

Distance vs. Power graph showing atmospheric backscatter for two different records.

System noise floor and 1/D signal visible for Z parameter and aerosol properties.
Altimeter Function

Design problems:
- Ramp rate counter accuracy (RC)
- Digital I/F bitshift error
- Temperature effects > calibration
- Altitude related effects > calibration
- Supply voltage impact > lack of HK data
- HRA alt used by CDMS above tested alt

![Graph showing FM B altitude related altitude correction factor]

- Correction factor: 20.99, 10.83, 20.145
- Measured altitude [m] vs. Correction factor [1]

![Graph showing HRA B relative temperature related altitude error]

- Linear (HRA B altitude)
- HRA B altitude
- Relative Error [1]
- Temp [deg C]
Surface Backscatter Measurements

Design problems:
• AGC / IF sampling times decoupled -> interpol.
• Lack of attitude data > sigma(0+/-x)

Calibration problems
• Some temperature effects unknown
• AGC calibration accuracy not dramatic
• Supply voltage > lack of HK data
Spectral Data for Topography Investigation

Design problems:
- Linearity of FM ramp very bad (after improvement !)
  => circuit concept
- Spectral resolution in PWA not very good
- Lack of attitude data

Calibration problems
- IF filter characteristics not calibrated
Atmospheric Backscatter Measurements

Design problems:
- Input stage noise temp ~ 263 K
  = -39 dBV (PWA)
- Measured: ~ -29 dBV = 2600 K !!
- no atm. BS data from lower alt (radar locked)

Calibration problems
- No / incomplete noise measurement data
Radar operations and new capabilities

Altitude measurement interleaved with science mode
- Once in lock, radar would not provide atmospheric data
- Radar can be 'kicked out' of lock to perform one atmospheric scan, then lock again

All relevant data sampled by same source
- Altitude, AGC, IF power

Advanced / new capabilities (specific hardware ?)
- Switching of radar beamwidth / direction -> radar mapping ?
- Surface mode ?
  ...... depends on priorities (system vs. instrument)
Conclusions

FMCW Radar Performance and Data Products

- Reliable, simple, lightweight system; range few 10m to few 10km
- Data products: Altitude, descent velocity, surface properties, atmospheric properties, topography, and others (wind, ..)
- Can deliver important science at very little additional mass / cost
- Output improved with auxiliary data (attitude, etc.)

Improvements for Future Applications

- A number of technical issues, but ... Most important:
- Use combined System / Instrument approach => Management issue
- Identify possible scientific utilization already during study phases
- If justified:
  - Use instrument specs in design requirements
  - Perform full science oriented calibration