Radiometric Calibration Techniques for Signal-of-Opportunity Reflectometers

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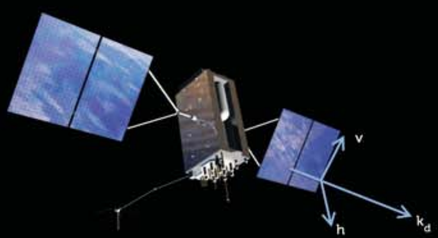


Transmitted electric field field as quasi-monochromatic phasor

Polarization and field strength — Information content retarded in time

$$E_t(t,R) = \hat{p}_t\left(\frac{P_t G_t}{4\pi}\right)^{1/2}\frac{e^{-jkR}}{R}\, a(t-R/c)\, e^{j2\pi f_D t}$$

Friis loss — Doppler shift referenced to observer

ABSTRACT

Bi-static reflection measurements utilizing global navigation satellite service (GNSS) or other signals of opportunity (SoOp) can be used to sense ocean and terrestrial surface properties. End-to-end calibration of GNSS-R has been performed using well-characterized reflection surface (e.g., water), direct path antenna, and receiver gain characterization [1].

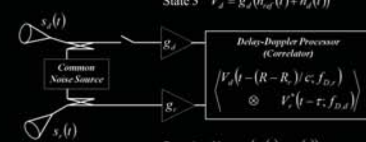
Here, we propose an augmented approach using on-board receiver electronics for radiometric calibration.

Using similar techniques long-term (days to weeks) calibration stability of the L-band scatterometer and radiometer on Aquarius/SAC-D has been achieved better than 0.1% [5]. Similar long-term stability would likely be needed for a spaceborne reflectometer mission to measure terrestrial properties such as soil moisture.

State 1 $V_d = g_d(s_d(t)+n_d(t))$

State 2 $V_d = g_d(s_d(t)+n_{cns}(t)+n_d(t))$

State 3 $V_d = g_d(n_{ref}(t)+n_d(t))$



State 1 $V_r = g_r(s_r(t)+n_r(t))$

State 2 $V_r = g_r(s_r(t)+n_{cns}(t)+n_r(t))$

MOTIVATION

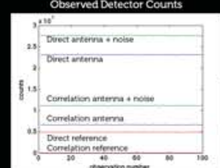
- Internal Calibration
  - Stabilizes receiver gains and offsets
  - Measures correlation efficiency
  - Defeats fluctuations with rapid and periodic updates
- Electronic Calibration Sources
  - Reference switch
  - Common noise source
  - Applicable to general SoOp reflectometers, e.g. [2].
- Similar to Conventional Microwave Instruments
  - L-band radiometer and scatterometers (e.g., [3]-[4])
  - Reference switches, noise diodes and loop-back circuits

METHODOLOGY

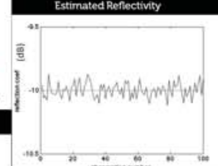
- Reference switching
  - Overcome thermal and $1/f$ fluctuations
  - Allows removal of receiver noise offset
  - Useful for low SNR direct antenna configurations
- Noise source firing
  - Allows measurement of receiver gains and correlation efficiency
  - Cross-power appears at zero delay
  - Simultaneously observe reflected cross-power when delay difference is much larger than coherence time of signal

SIMULATION RESULTS

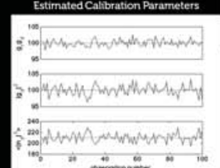
Observed Detector Counts



Estimated Reflectivity



Estimated Calibration Parameters



SIMULATION & CALIBRATION

- Simulation parameters (static ground system)

Instrument parameters in units of counts (correlator output) and Kelvins (P/kB)					
Antenna Gains	0 dBi	SNR of direct look	10 dB	Sky temperature	10
RF Gain	100	Receiver BW and Signal Type	10 MHz QPSK	Reflected look antenna temp.	150
Receiver noise temp	200	Reference load temperature	280	Noise source effective temp.	450

- Calibration Equations

$$g_d g_r^* = [K_{rd}(\text{State 2}) - K_{rd}(\text{State 1})]/T_{CNS}$$

$$|g_d|^2 = [K_{dd}(\text{State 2}) - K_{dd}(\text{State 1})]/T_{CNS}$$

$$\langle |n_d|^2 \rangle = K_{dd}(\text{State 3})/|g_d|^2 - T_{ref}$$

Cross-correlation function with range-tracking

Receiver gain ratio

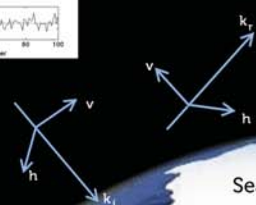
Reflectivity $$|\Gamma|^2 = \frac{G_d}{G_r}\left|\frac{g_d}{g_r}\right|^2 \left|\frac{K_{rd}((R_r-R)/c)}{K_{dd}(0) - \langle |n_d|^2\rangle |g_d|^2}\right|^2$$

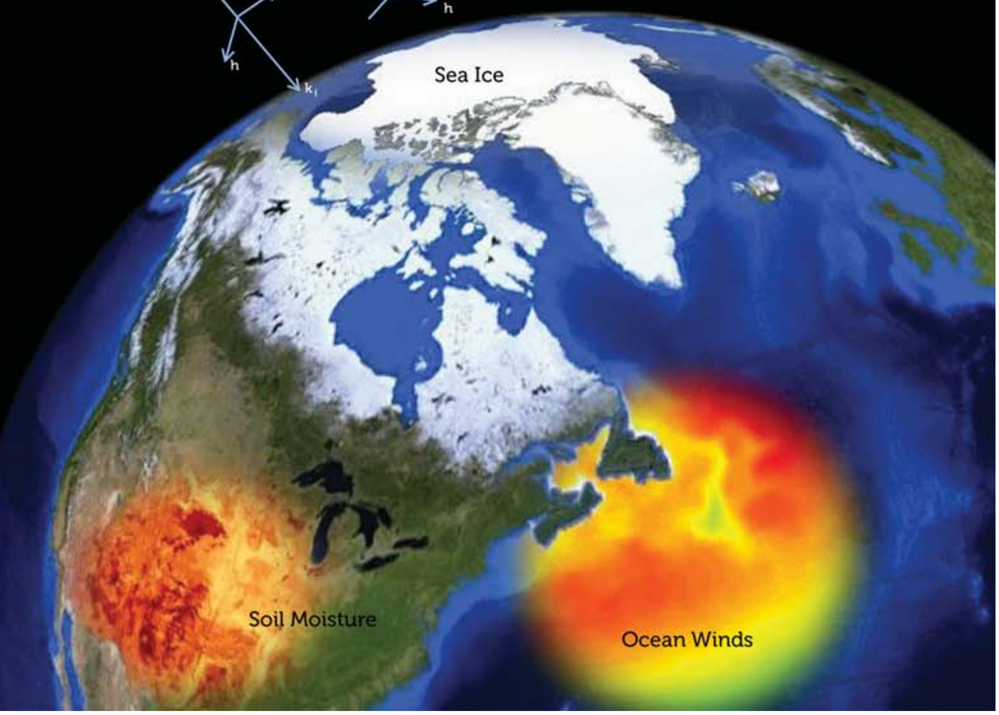
Antenna gain ratio

Offset caused by sky and receiver noise

Auto-correlation function at zero lag

(Doppler-shift notation removed for simplicity – ground-based case)





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