Design of a sUAS-based FMCW Microwave Radar for Snow and Soil Moisture Measurements

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Abstract

The Remote Sensing Center at The University of Alabama has developed a prototype FMCW microwave radar for measuring snow depth and soil moisture. The radar has a 4 GHz bandwidth, providing approximately 6 cm range resolution. Delay line testing yields near-ideal impulse response and very linear chirp. The radar has been integrated with a small unmanned aircraft system (sUAS). A custom 4x2 patch antenna has been developed for the operating frequency of the prototype radar.

Objectives and Background

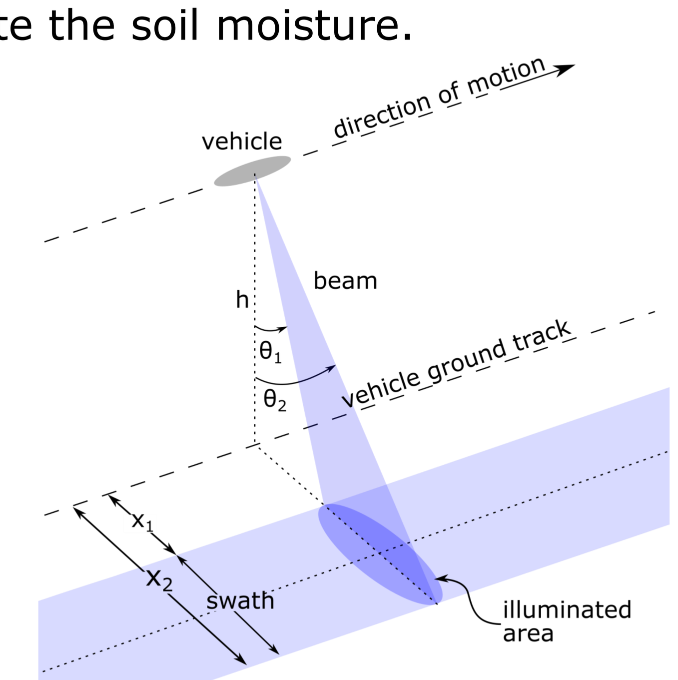
A prototype radar to integrate with a UAS has been designed to accomplish the following tasks:

- Measure snow and ice depth
- Estimate soil moisture from backscatter measurements
- Estimate and correct for vegetation effects

A radar transmits a linear frequency-modulated chirp. That signal propagates through space, reflects off targets, and reradiates the receiver antenna. The received signal is mixed with the original transmitted signal, producing beat frequencies that correspond to unique time delays.

In snow and ice measurements, interfaces such as the air-snow and snow-ground interface reflect a portion of the energy. Taking an FFT of the received signal directly provides a map of the layers within the snow.

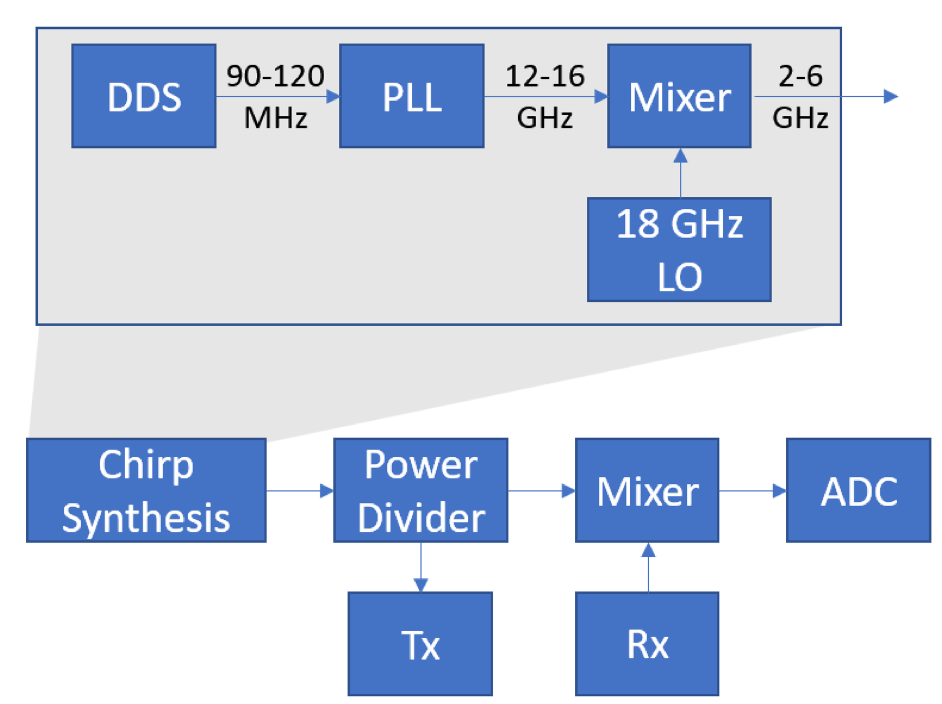
For soil moisture measurements, a side-looking configuration can map the time delay to an angle of incidence. This is needed because backscatter varies with soil moisture and angle of incidence. Backscatter measurements can the be used to estimate the soil moisture.



Radar Prototype

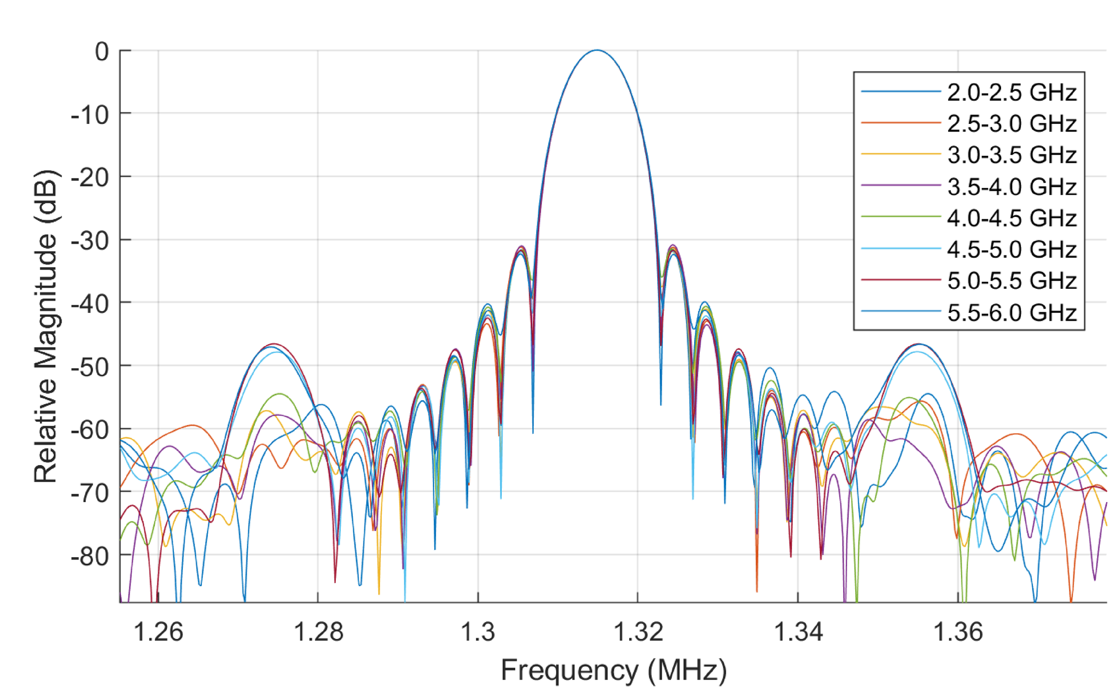
Parameter	Specification
Operating Frequency*	2-6 GHz
Bandwidth*	4 GHz
Chirp Length*	2 ms
Resolution	6 cm
System Weight	11 lb
Transmitter Power	15 dBm (32 mW)
Power Consumption	40 W
Enclosure Size	18 x 15 x 5 in.

*configurable



High-level system diagram

- A highly configurable chirp synthesis system allows for fine-tuning chirp parameters
- Delay line tests yield near-ideal impulse response.
- Very linear chirp performance
- Good radar performance enables faster data processing and helps to provide results within a few hours of data collection



Impulse response over 500 MHz sub-bands.

UAS Integration

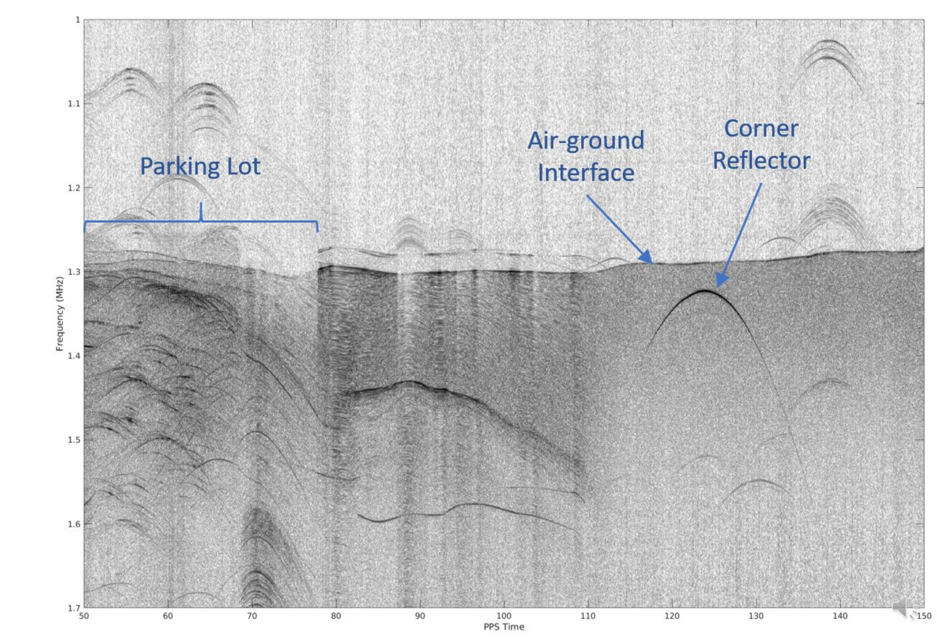
Parameter	Specification
Airframe	Xfold Dragon x6 Multirotor
MTOW	55 lb
Endurance w/ payload	10 min*
Batteries	12-cell, 22 Ah LiPo x2
Radar INS	VectorNav VN-200
Footprint	2 m diameter
Flight Controller	Pixhawk 2.1 "Cube"
RC/Telemetry Link	DragonLink 433 MHz transceiver
Radar Antenna	Custom 4x2 patch array

*Electric propulsion only. Endurance can be increased using the hybrid gas propulsion system.

We have integrated the radar with a small Unmanned Aircraft. The airframe is the Xfold Dragon X6 multirotor. It is 2m in diameter, and it has a maximum takeoff weight of 55 lb. With the current prototype radar payload, it has an endurance of about 5-7 minutes using the electric propulsion system. An included hybrid gas propulsion system can be equipped to increase the endurance. Future weight and size reduction efforts will improve endurance significantly.

Results & Conclusions

We flew the aircraft over the intramural fields at the University of Alabama at an altitude of 100 m above the ground. The echogram below shows a few points of interest from the maiden flight with the sUAS. At PPS time 124, you can see the strong return from the corner reflector we placed approximately 40m to the side of our ground track. You can also see the air-ground interface at a frequency of about 1.3 MHz, which corresponds to the 100m altitude.



Planned Work

- Fully develop soil moisture processor
- Develop algorithms to estimate and compensate for vegetation
- Collect and process snow measurements
- New antenna
  - Dual polarization
  - At least 5 dB higher gain (10 dB SNR improvement)
  - Wider bandwidth
  - Integral power divider
- Miniaturization - estimated 75% reduction in radar weight
- Fusion of radar measurements with INS for GNC

References

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[2] J. Cihlar and F. T. Ulaby, "Dielectric Properties of Soils as a Function of Moisture Content," 1974.
[3] F. T. Ulaby, P. C. Dubois and J. van Zyl, "Radar Mapping of Surface Soil Moisture," Journal of Hydrology, vol. 184, pp. 57-84, 1996.

Acknowledgements

Special thanks to Shriniwas Kolpuke, Tuan Luong, Natalie Nickerson, Adam Horstman, Stephen Jones, and Abhishek Awasthi.