TESTING OF A PROTOTYPE LOW COST AND LOW POWER FMCW RADAR IN THE ANDES

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A prototype of a low cost and low power 10GHz Microwave Frequency Modulated Continuous Wave radar was developed and tested in the Andean snowpack during the Austral winter of 2013 at three field locations; Chapelco Ski Resort-Argentina, Villarica Ski Pucon Resort-Chile, and Las Leñas-Argentina (Figura 1). A new generation of compact and low cost radars will make it easier for researchers to study snow at remote locations and to deploy remote instrumentation in the field due to their low power requirements.

Figure 1: Field research locations.

Snow stratification is the natural result of weather variation, where temperatures, precipitation rate, wind, humidity, and many others factors interact to generate snow layers with different densities, liquid water content, crystal size and type, impurities, and anisotropic or isotropic properties. These layers typically result in discrete interface with defined boundaries. The contrast between these layers produces reflections of electromagnetic waves used in radars. Radar reflections are based in the contrast of snow permittivity at various layers, which is primarily affected by the available free water, and snow density (Marshall *et al.* 2008) (Figure 2).

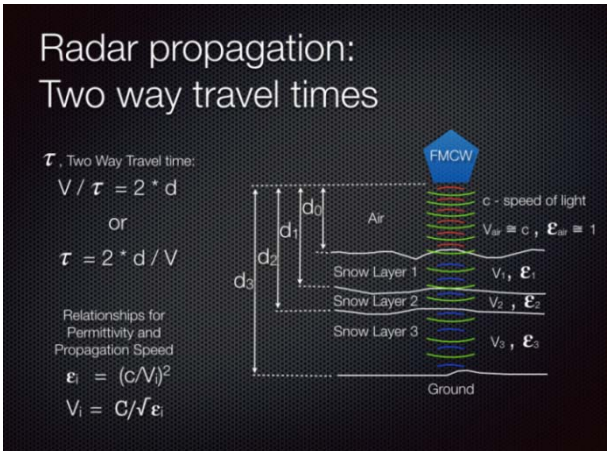

Figure 2: Snow stratigraphy from FMCW reflections. Green color corresponds to radar signal, red to radar reflection at the snow surface propagating through air and blue to radar reflections from the snowpack contrasting layers.

Frequency Modulated Continuous Wave Radars used by Boise State University Cryosphere team to conduct snow stratigraphy research operate in the 4 to 25 GHz range. A low cost, low power, and compact FMCW X-band radar operating in the 10 GHz range was used for this study. The starting frequency for the prototyped radar is 9.25 GHz, with a bandwidth of 1.5 GHz, and a linear sawtooth continuous wave sweep time of 100 ms.
The Austral winter of 2013 was characterized relatively high isothermal levels in Northern Patagonia, inclusive of Chapelco and Villarica, and a shallow snowpack in the Mendoza region, where Las Leñas is located. Two field days of the campaign occurred immediately after significant rain in snow events, with one at Villarica, the other at Chapelco.
Density, amount of liquid water, as well as temperature and hardness profiles were recorded. The amount of liquid water was estimated with a Denoth snow capacitance meter, which combined with density data allows to independently compare the estimates of snow permittivity based on FMCW radar analysis for the conditions observed this year in the Andes.
Table 1 provides an example of the study results to be presented at "XIX Congreso Geológico Argentino'. These propagation velocities were used to contrast radar estimated free water in the snowpack with Denoth measurements.

Field recorded Distance [cm]	Estimated EM prop velocities [cm/s]		Permittivity
32	1.55e+10	+/- 0.5 %	3.77
44	1.26e+10	+/- 1.5 %	5.69
50	1.76e+10	+/- 4.2 %	2.91
68	2.10e+10	+/- 1.7 %	2.04
81	2.05e+10	+/- 2.3 %	2.14

Table 1: FMCW radar generated stratigraphy for Chapelco snowpack. Distances between layers were recorded using radar reflections and validated with field observations. Inversion techniques were applied to obtain snow propagation speeds and permittivities.

The research campaign targeted contrasting geographical locations to expose the low cost and low power FMCW radar system to challenging conditions. The snow at these locations varied significantly in density and free water content. These conditions offered an ideal field laboratory to test the prototype FMCW radar.
In summary, the radar prototype operated reliably during the research campaign in the Andes. No hardware issues were identified, suggesting that the use of these low power and low cost microwave transcievers are ready for field use. The cost of the system prototyped is in USA$ 2000 range, making this technology accessible to cryosphere, hydrologists, and avalanche researchers. Tools like this portable microwave radar is important for field researchers to estimate snow water equivalent, and to make easier the generation of snowpack stratigraphy. The low power requirements as well as compact design of the prototyped radar enables deployment at remote ground stations.
The portable FMCW radar system developed by Boise State University for snow research weights 1.36 kilograms and occupies a volume of 3740 cubic centimeters. The complete system consist of a radar chip, controller board, 15dB radar antenna with wave guide, Raspberry-PI computer with LED display and Input interface running linux operating system. Radar scan data is transferred to computers for FFT processing via internet.
The microwave FMCW radar prototype tested during the 2013 Austral winter in the Andes is a rather unique system at the time of this writing, that can be characterized as a first for snow research due its low cost and portability. The prototype development was completed in June 2013 and tested promptly in the Andes. Results from the South American campaign allowed to develop a second generation of even smaller and lower power radar versions. Two portable radar systems operating at 10 GHz and another at 25GHz are currently being tested during the 2014 Northern Hemisphere winter. Results from these testing will be presented.

Marshall, H.P. y Koh, G. 2008. FMCW radars for snow research, Cold Regions Science and Technology, 52: 118–131 p.