Gated UWB FMCW/SF Radar for Ground Penetration and Through the Wall Applications

Svein-Erik Hamran, Tor Berger, Leif Hanssen and Mats Jørgen Øyan
FFI
P.O. Box 25
2027 Kjeller
NORWAY

Svein-Erik.Hamran@ffi.no

ABSTRACT

A gated FMCW and Step Frequency (SF) radar system has been developed. The radar is covering the frequency range 0.5 – 3 GHz. The prototype system can be run in either SF or FMCW modes and both modes can be run either CW or gated. The radar is gated so that the receiver is switched off when the radar is transmitting. This enables single antenna operation or removal of the leakage between the transmitter antenna and the receiver antenna. Strong close reflectors saturating the receiver can be efficiently removed increasing the radar system performance. System performance is important for through the wall radars and ground penetrating radars. The radar system has been used for detecting moving people behind walls and detection of breathing and heart beats. The radar system has also been used as a prototype for the shallow GPR on the ExoMars mission to the planet Mars. The radar was successfully field tested in April 2008 in mapping layers and detecting ground ice in permafrost.

1.0 INTRODUCTION

There are several ways to generate a wide bandwidth radar signal. The most common way is to apply a short dc pulse to an antenna. With steep edges this pulse contains a very wide spectrum. The antenna works as a band pass filter and radiates part of the spectrum. The received signal is amplified and sampled in the receiver. If the bandwidth is several GHz the standard method for sampling the signal is by taking one receive sample for each transmitted pulse. This is called stroboscopic sampling or time repetitive sampling and is a standard technique used in digital oscilloscopes. A radar range profile is built up by transmitting several pulses and changing the delay time for each sample.

All the UWB-waveforms used in radar have different ways to reduce the sampling frequency in the receiver. In FMCW the received signal is multiplied with the transmitted signal and only the beat frequency is sampled. In a step-frequency system the frequencies are transmitted one by one and only a low sampling frequency is needed. In this article a UWB-system that can be used as either a step-frequency or a FMCW is described in section 2. The radar system has been used as a prototype for the WISDOM GPR to be on the ExoMars mission and as a through the wall radar. Results from both applications will be shown.

The WISDOM instrument is one of the instruments that have been selected to be part of the Pasteur payload of the ESA ExoMars mission , and . The main scientific objectives for the Pasteur payload on board the mission rover are to search for traces of past and present life on Mars and to characterise the shallow subsurface. To do this the rover of the mission has a drill that can obtain samples of the subsurface down to a depth of approximately 2 meters. The exploration of the sub-surface of the planet is essential since chances that life has survived on Mars increase with increasing burial depth. The Ground Penetrating Radar, WISDOM onboard the rover is the only mean to obtain information about the sub-surface before drilling. The WISDOM instrument objective is the exploration of the first ~ 3 meters of the soil with a very high range resolution in accordance with the objectives and expected capabilities of the drill exploration.

2.0 RADAR DESIGN

Fig 1 shows a block diagram of the FMCW radar design. The discussion of this section also applies to the SF radar except that the FMCW synthesizer in Fig 1 is replaced by a SF synthesizer. The radar is a gated frequency modulated continuous wave (GFMCW) system with frequency range from 500 MHz to 3 GHz. The FMCW synthesizer is a combination of a Direct Digital Synthesizer (DDS) and a Phase Locked Loop - Voltage Controlled Oscillator (PLL-VCO). Typical sweep times for the FMCW signal are from about 1 ms and up. The output is a signal from 5 GHz to 7.5 GHz. A Local Oscillator (LO) synthesizer is made by a PLL-VCO generating a signal of 8 GHz. The FMCW signal is mixed with the 8 GHz LO-signal followed by low pass filtering to produce a resulting FMCW signal from 500 MHz to 3 GHz. The transmitted signal is gated at the Tx front end, and this gating is controlled by a second DDS. The received signal is amplified, gated and homodyned with the FMCW signal, followed by a low pass filtering and sampling with an analogue to digital converter (ADC) of 16 bits. Typical sampling frequency at the receiving end is 1 MHz.

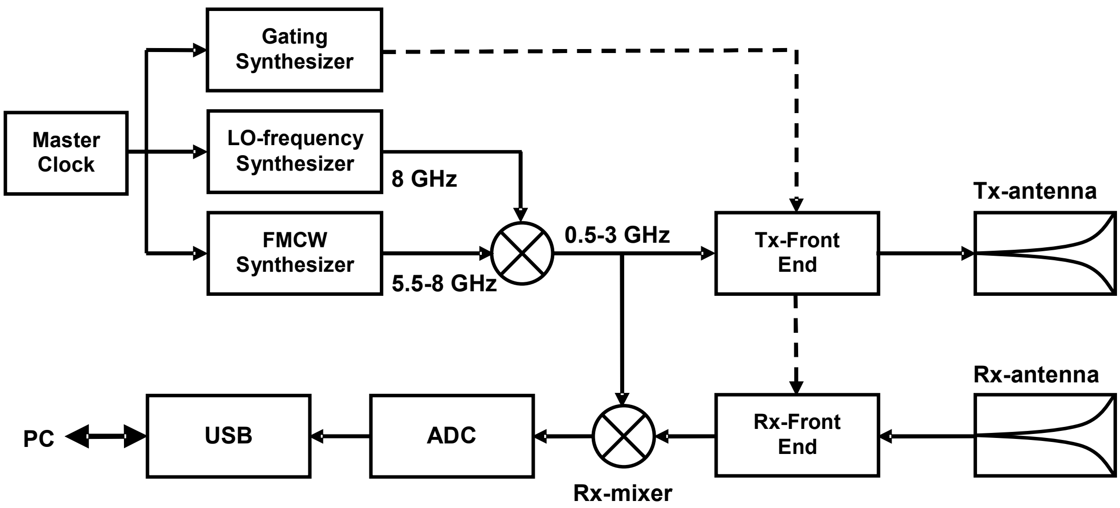
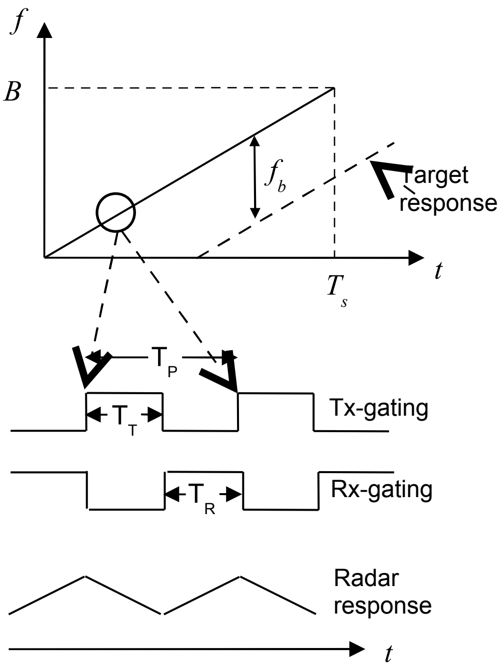


Figure 1: Block diagram of radar design

The sweeping and gating scheme is shown in Fig 2, and is also described in and . Typical values of sweep time and gating frequency could be 1 ms and 20 MHz, respectively. During the sweep time the transmitted signal is then switched on and off with a duration of 25 ns. When the transmitted signal is switched off, the receiver is switched on, and vice versa. The radar response due to the gating is the convolution between the transmitted square waveform and the receiver gating signal as shown in Fig. 2. The result is that the direct signal between the transmitter and the receiver is effectively removed, and we can also reduce the response from strong reflectors close to the receiving antenna. By introducing this type of gating it is also possible to use a single transmit and receive antenna instead of two separate ones. A transmit and receive gating frequency of 20 MHz gives gating period T_P of 50 ns, and the maximum radar responses are at odd multiples of 3.75 m. Minimum radar responses are at even multiples of 3.75 m.



B - Bandwidth

T_s - Sweep time

f_b - Beat frequency

c - Speed of light

Range to target : $R = \dfrac{cT_s}{2B} f_b$

Max response : $R = n\dfrac{cT_P}{4}$, n odd

Min response : $R = n\dfrac{cT_P}{4}$, n even

Figure 2: Illustration of sweeping and gating scheme

The components of Fig 1, except for the PC and the antennas, are put on two printed circuit board (PCB) measuring 16x19 cm, see Fig 3.. The radar is controlled and data is read through the USB interface. The antennas used in the experiments are different types of Vivaldi antennas.

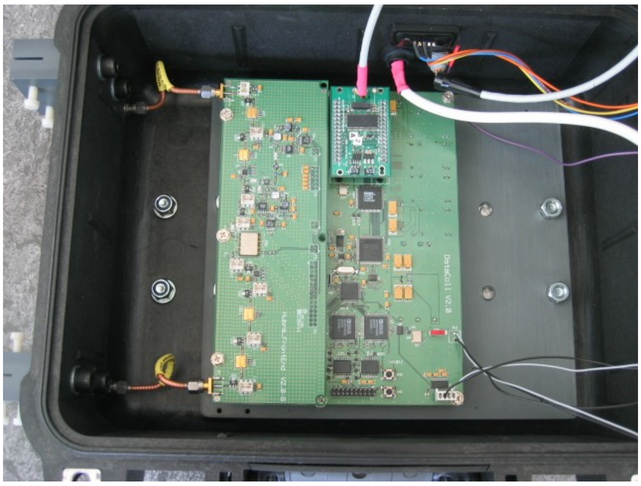


Figure 3: The radar cards in the WISDOM prototype are mounted in a Pelicase.

3.0 GROUND PENETRATION RADAR

The WISDOM-GPR prototype was tested in field on Svalbard in April 2008. The test area is shown in Fig 4. Earlier the glacier Comfortlessbreen was extending all the way to the moraine. The lower part of this glacier was covered with fluvial sediments coming from areas higher up on Uversbreen. This has resulted in an area of buried glacier ice covered by 2-3 meters of sediments, see Fig 4. The permafrost in the area is believed to go down to 150 meter. The active layer is estimated to be 2 meter. The ground was totally frozen at the time the measurements were taken and can therefore be considered as an area of permafrost.

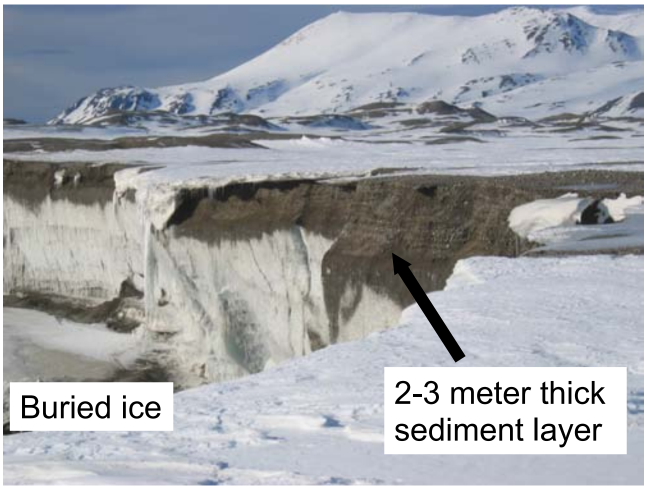


Figure 4: In the field test area glacier ice is covered with a 2-3 meter thick layer of sediments.

Other GPR systems have already been tested in Mars analog terrains, both in frozen and unfrozen ground conditions , . We will in the following show some preliminary results taken with the prototype system. The WISDOM radar was run along several profiles in the area in Figure 4. The same profiles were also mapped with a commercial GPR system RAMAC from Malå. A 500 MHz shielded antenna was pulled in a plastic pulk and a 50 MHz Rough Terrain Antenna was pulled behind the scooter sled.

Fig 5 show a 40 meter long profile running from the moraine and away from the moraine. The display is more intensity based as the plotting normal GPR profiles did not turn out nice since the number of samples was too large. The first 10 ns are gated away. In these measurements the antennas were mounted directly on the radar electronics box without cables. Due to the rise and decay times in the switching gates used this generated a blanking zone close to the surface. Other antennas that were connected with a cable length to the electronic box yielded a response from the surface and down.

We see that the radar system can penetrate the first sediment layer and that the sediment/ice interface is seen all along the profile length. The velocity of this sediment layer was estimated to 125 m/ns using reflecting hyperbolas at the sediment/ice interface. The thickness of this layer varies from 2-3 meters.Below the first sediment layer glacier ice with varying thickness from zero at the start of the profile to 3 meter at the end can be found. The bottom of the ice is seen all along the profile. Below the ice layer, moraine material with higher conductivity is found. There is no layering inside the moraine so that the radar signal is mainly scattering from rocks and other in-homogeneities inside the moraine. Scattering form these rock can be seen down to 1.5 meter into the moraine.

Figure 6 shows a zoomed in version of the first 50 ns and 24 meter of the profile in Figure 5. The reflection just under 10 ns is believed to be the snow sediment interface. At 40 ns the reflection from the sediment/ice interface is seen. In between scattering from rocks and reflections from broken layers can be seen.

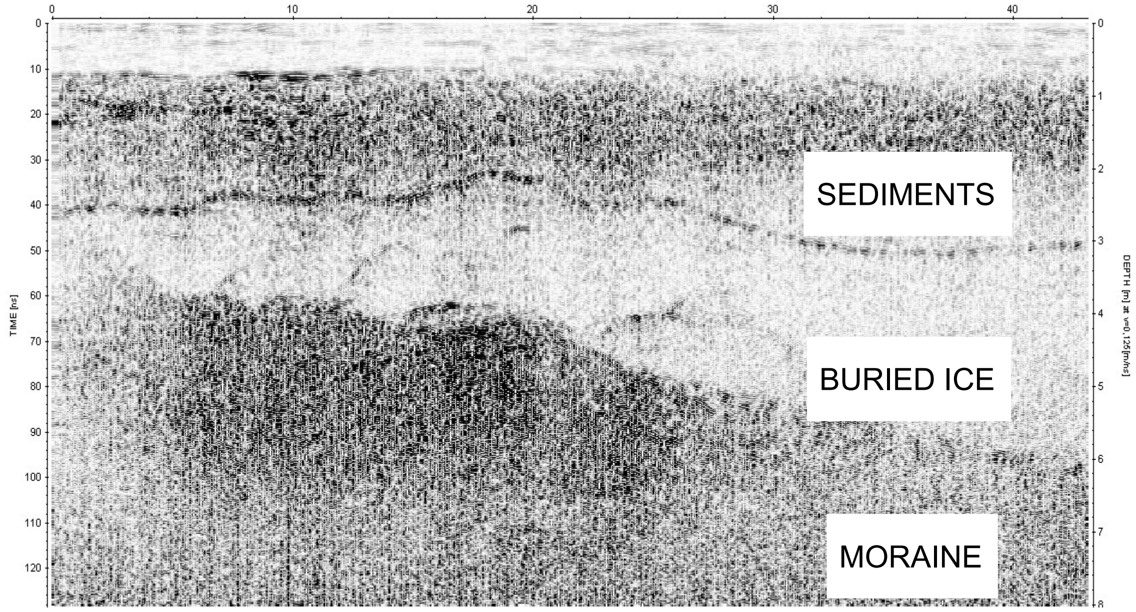


Figure 5: A radar profile showing penetration through the upper sediment layer, through the glacier ice and down into the moraine materials underneath.

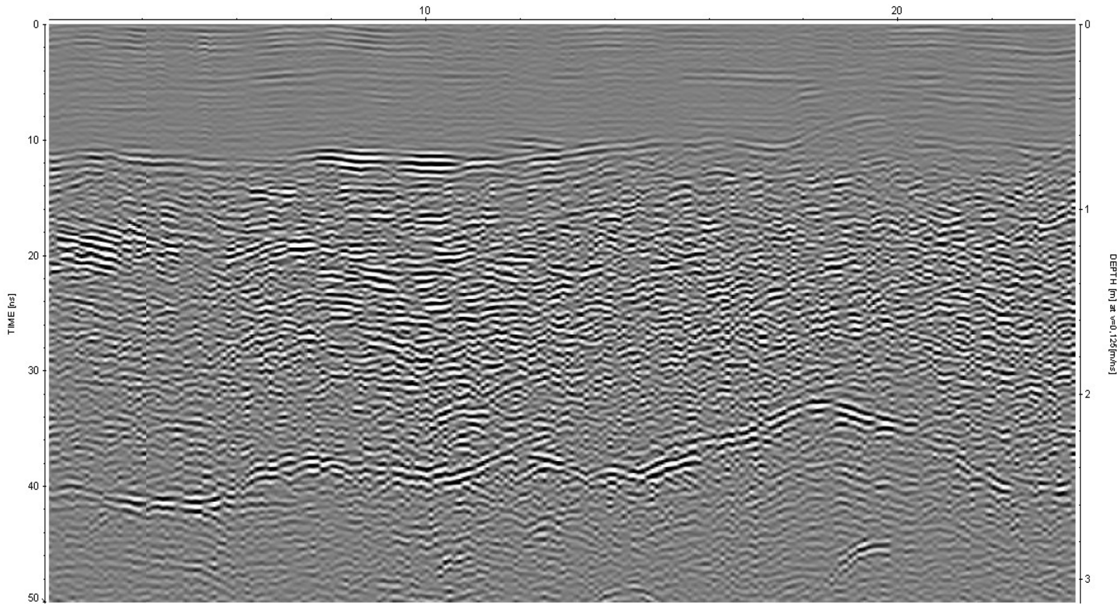


Figure 6: Zoomed in version of the profile in Fig 5 showing the first 50 ns and 24 meters.

4.0 THROUGH THE WALL RADAR

Through the wall and life sign detection with radar has been published by several people -. In this section measurements that have been performed with the design described above will be presented. The radar prototype was put behind an internal wall of thickness 8 cm, and a person was in the other room. Both rooms were equipped with chairs, tables, projectors, PCs, radiators, etc. The size of each room was about 15 m^2. No specific measures were taken to reduce multiple reflections or other interference. In this way a realistic scenario for detecting people was chosen. The prototype board was not shielded in any way, which it to a certain degree would be in a complete system. The first measurement result is shown in Fig 7, where a male person is walking towards and away from the radar. As we can see the person started at a distance of about 3.5 m from the antenna, moving closer to the wall, and then moving back to about 3.5 m. A Fast Fourier Transform (FFT) is applied to the received frequency domain signal and the mean slow time signal value is subtracted from the signal at each range bin. The real value of the resulting signal is shown in Fig. 7. The pulse repetition frequency (PRF) was set at 150 Hz, i.e. well beyond the expected Nyquist frequency. From this we may conclude that the problem of detecting a person walking behind a wall is not a difficult one. What would be the natural next step is to apply a tracking algorithm to the data, and thereby be able to track one or several objects within the room. This is included in the designs of some commercial systems - .

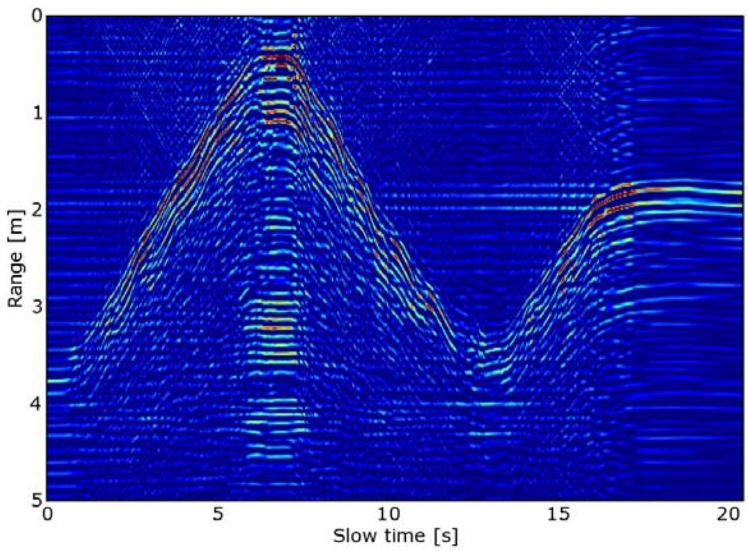


Figure 7: Measurements of person walking behind internal wall

Probably the most difficult detection task is the case when a person is holding his breath. A person is sitting in a chair at about 85 cm behind the internal wall of 8 cm. He is instructed to hold his breath and otherwise try not to move any part of his body. Fig 8 displays the results for this situation. The slow time profile at 85 cm is extracted from the data, and this profile is band pass filtered with filter limits at 0.75 Hz and 3 Hz. We see a heartbeat pattern that has a good match to some of the ACG patterns reported in the literature - .

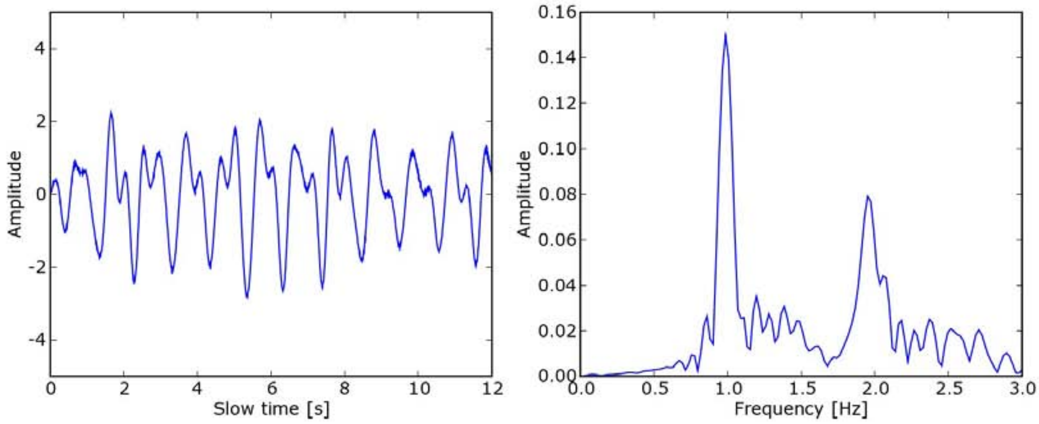


Figure 8: Filtering of the slow time profile at 0.85 m as displayed in Fig. 9. Heartbeat frequency components are seen

5.0 CONCLUSION

An ultra wideband radar design for detection of vital signs and ground penetration radar has been described, and measurements have been performed. The GPR showed penetration in permafrost down to several meters. Layering could be seen and the sediment buried ice interface could be detected at 2-3 meters depth. We have also demonstrated the feasibility of using this technology to detect people in situations of low optical visibility, and even behind barriers. The radar system is very sensitive to even small body motions. It has been shown that detection of a person walking or breathing can be done without much post processing of the received signal, while the detection of heartbeats requires more signal processing. The results reported in this paper are the first measurements performed with the radar prototype and further work is needed to develop signal processing algorithms for detection and possible tracking of moving objects.

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