Mapping The Underworld (MTU) – Ground Penetrating Radar

Dr S.R. Pennock, H. Jenks, G. Orlando, Dr M.A. Redfern, Dr A. Naji, Dr. Q. Zhang

Department of Electronic and Electrical Engineering, University of Bath.

EPSRC Engineering and Physical Sciences Research Council

Mapping the Underworld

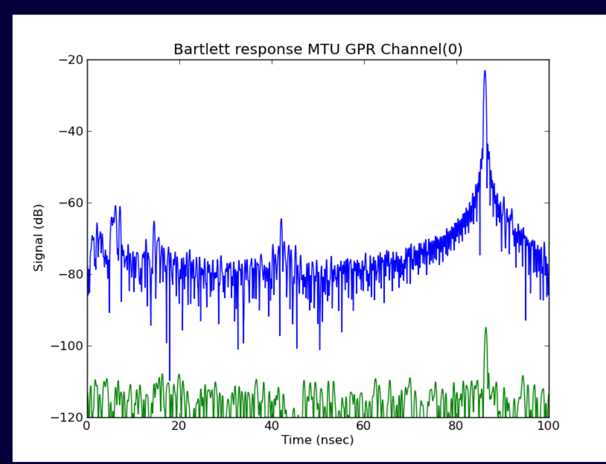
www.mappingtheunderworld.ac.uk

Ground Penetrating Radar – electronic system developments

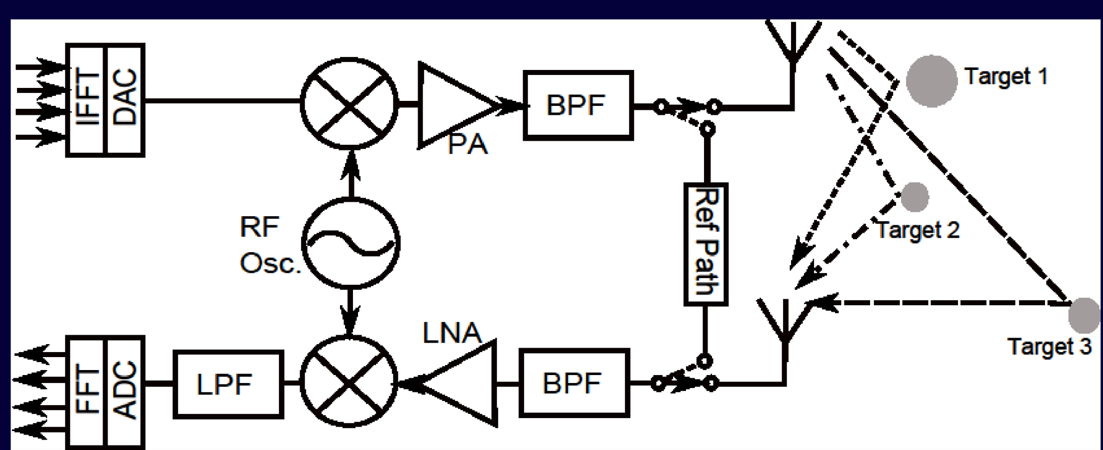
Part of the MTU multi-sensor project looks into GPR electronics to investigate and develop new concepts in the electronics, with an aim to facilitate the use of quite widely separate transmitter and receiver points.

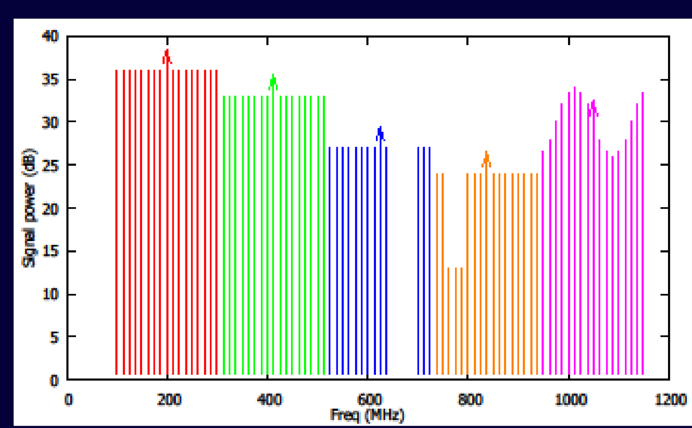
Investigations have been carried out into Step Frequency Continuous Wave (SFCW) and the novel Orthogonal Frequency Division Multiplexed (OFDM) radar schemes. In radar systems linearity requirements are often more stringent than in communications systems as the radar targets of interest are often much weaker than clutter targets that are not of interest.

SFCW. The SFCW scheme developed was observed to operate over a dynamic range of about 90dB. This is illustrated in the diagram to the right where a single path at 87 nsec was observed as 80 dB of attenuation was added to the path. The system response at the higher power level shows that the ability to see one target in the presence of another target is limited to the weaker response needing to be within 50dB of the stronger response.

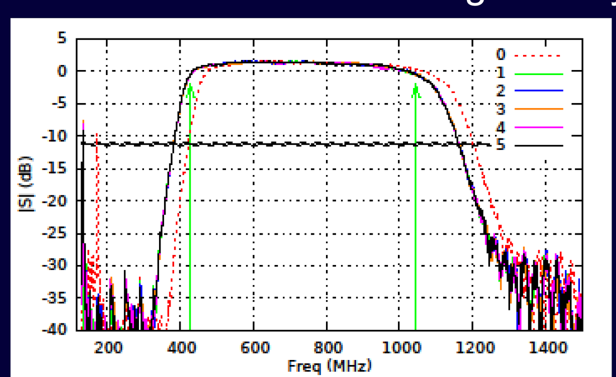


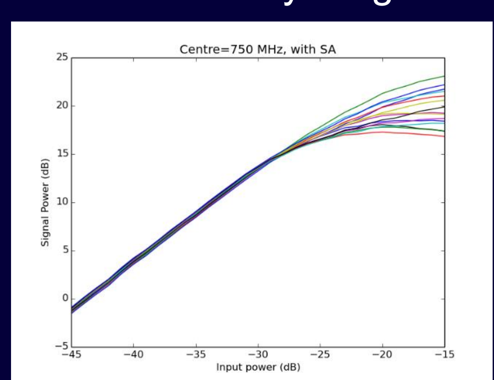
OFDM. The recent development of applying OFDM techniques to radar offers the potential for quicker data acquisition by measuring blocks of spectrum with a very high degree of control over the radiated frequency spectrum. As such the OFDM scheme gives very sophisticated control over the radiated signal spectrum and 'pulse shape' by simply changing the data presented to the input IFFT block. This allows the radar to meet radio regulatory requirements and dynamically adapt to the local radio conditions where a GPR is operating to avoid interference.

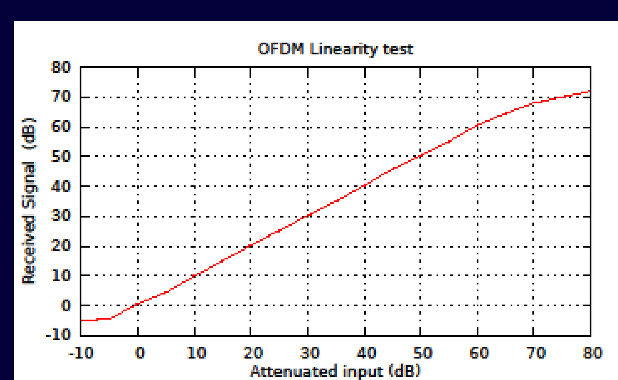




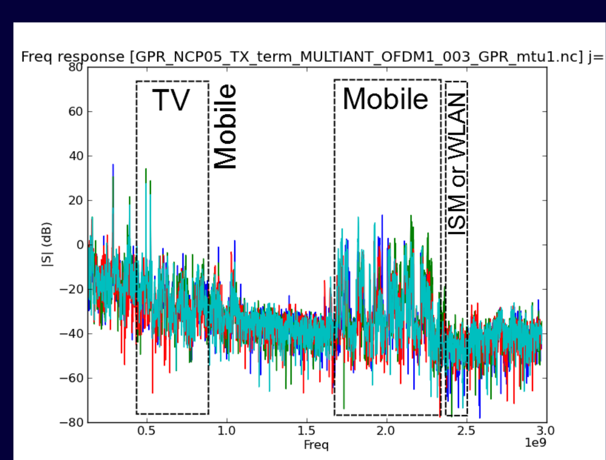
Recent development of the OFDM system have included rapid data re-measure for averaging and more sophisticated data processing techniques. The use of Spectral Avoidance has been developed to reduce the influence of non-linearities in the system and thereby increase the upper limits of the dynamic range. The dynamic range of the OFDM system has been observed to be about 80 dB, where the system becomes limited by the dynamic range of the 14-bit ADCs. Some deconvolution is needed to remove low level features that repeat every 25 nsec, corresponding to the 40MHz of the sub-bands used. Higher speed ADCs would move these features to longer delays outside of the delay range of interest.





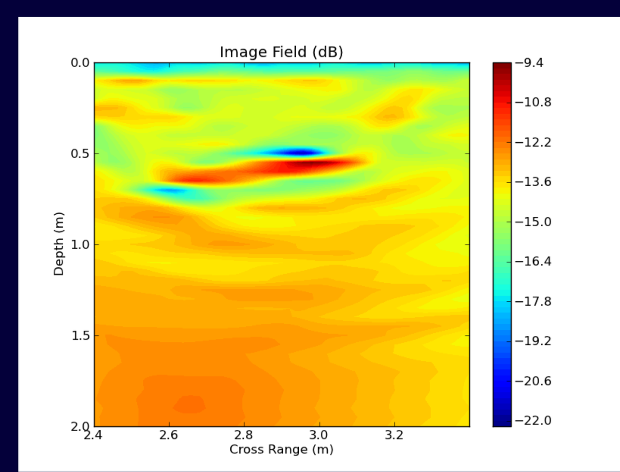


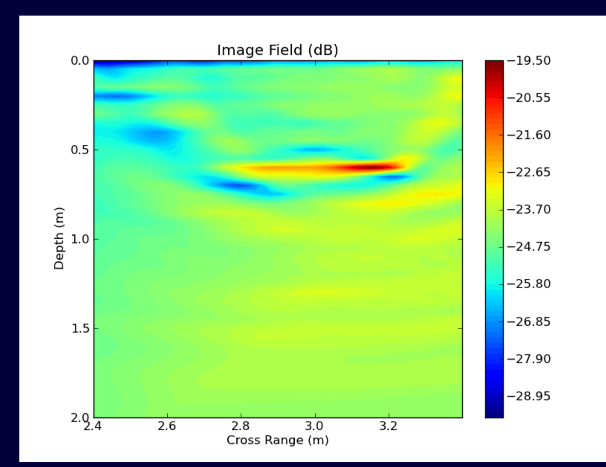
Spectrum Observations: Recent measurements show the radio spectrum encountered at a test site. The TV and Mobile signals received are much larger than those reflected from buried targets, and the spectral interference will depend on the test site location. Better shielding of antennas will improve this, but not by 40dB-50dB. The OFDM and SFCW schemes allow these interfering signals to be simply ignored, rather than needing to be processed out of the received signal. In addition the measures can be taken at each measurement site so that the system can adapt to the site, and during measurements dynamically adapt to the interference.



GPR – data interpretation

The traditional display of GPR data as a B-scan produces a hyperbolic signature for each target – requiring quite skilled interpretation by the surveyor. One strand of the research has looked into 'focussing' the data into responses at the target positions. Using a commercial GPR and estimates of the permittivity of the ground from the GPR data and the Knowledge Based System the images below were obtained. The 'signature' of a target in the GPR data is a peak and a trough, and appear as a red peak and a blue trough in the images.

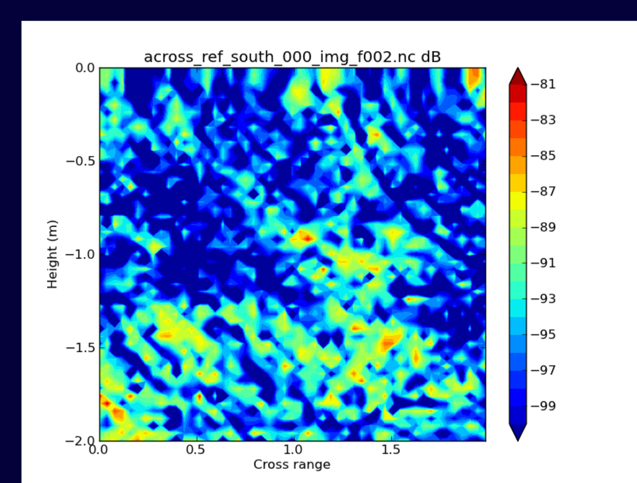




The target signature shows at different cross range distances as the buried pipe lay at a slight angle to the measured sections. The range of values in the image is typically less than 6 dB and the target signature tends to spread horizontally. This is mainly due to the GPR data being taken every 2.32 cm. The high density of measures produces a considerable false contribution to the image where there is no target, and there are many contributions from all the very similar measures recorded near the target position.

SFCW measurements and data interpretation

Measurements at Blagdon and the J.K. Guest test site taken with the MTU GPR operating in its SFCW mode in the 'Mobile Laboratory'. An array of Lunula Loop and Lunula Dipole antennas developed during the research were used, along with the signal processing ideas developed during the research.

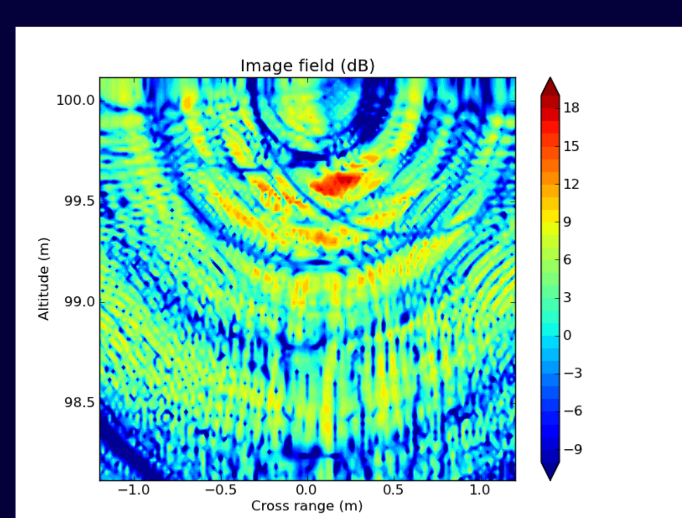


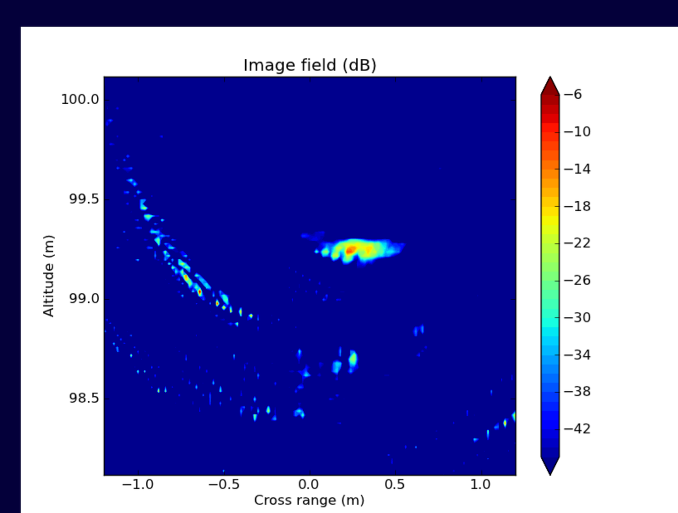
A typical response is shown on the right, where a single target is expected to produce a single peak (red) response. There are a number of responses indicating targets, but this ground is thought to hold just one significant target.

Closer examination of the antenna array using Finite Difference Time Domain reveals that there is quite significant multiple reflection of the radar signal within the antenna array. This results in a single target producing multiple responses. The multiple reflections set up in the array produce a difficulty in deconvolving the radar responses – the deconvolution calculations change with the position of the target.

Using discrete dielectric loaded bicone antennas produced a much less cluttered responses as shown in the figures below. These were obtained with ten measures spaced 20cm across the ground.

On the left the range of image values is 30 dB, much higher than achieved with the more closely spaced data from the commercial GPR above. The positional resolution at the -3 dB points is a few cm. On the right is the image obtained at a parallel section about 1m further along the run of the buried pipe. In this case the range of values in the image is 40 dB.

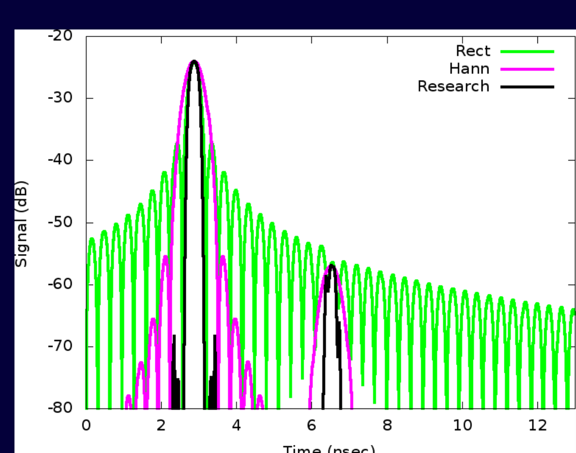




SFCW and OFDM GPR signal processing – improving target resolution

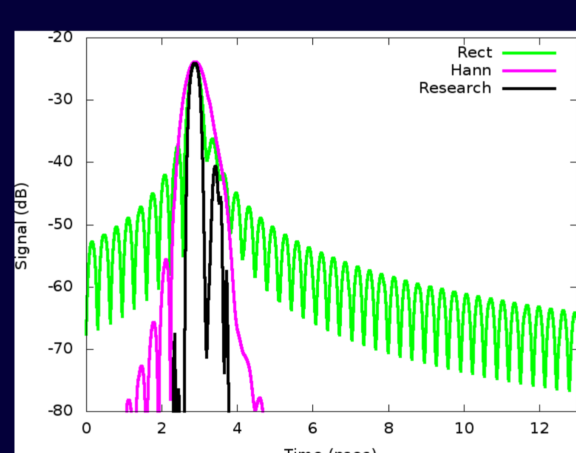
In the SFCW and OFDM schemes the basic measure is taken the frequency domain, and Inverse Fourier Transform techniques convert this to the more usual time domain representation of 'pulses' at a time delay corresponding to the 'echo time' to a target. A radar system generally needs to find weak (deeper) targets in the presence of strong (shallow) targets.

The standard Rectangular window response (green) is narrow, but with high side lobes. These side lobes can easily mask the deeper , weaker target at a delay of 6.5 nsec. The weaker target produces a rather minor disturbance in the green traces.



Applying window functions such as the Hann window reduces side lobes, but broadens the main lobes – as shown in magenta. The two targets are resolved but with less precision in time delay, and less ability to resolve closely spaced targets.

Research on superimposition and normalisation of multiple IFFT evaluations has resulted in the black traces where the response of a target has the same narrow width as the Rectangular window and with better side lobe reduction than the Hann window. The resolution of the target response into a single narrow response produces more accurate resolution of targets.



UNIVERSITY OF BIRMINGHAM · UNIVERSITY OF BATH · EPSRC Engineering and Physical Sciences Research Council · UKWIR · UNIVERSITY OF LEEDS · The University Of Sheffield. · UNIVERSITY OF Southampton