A NEW ULTRA WIDEBAND, SHORT PULSE, RADAR SYSTEM FOR MINE DETECTION

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INTRODUCTION

An experimentation is described for measurement of UWB transient scattered responses from different targets. The measurements are performed using a new UWB Synthetic Aperture Radar (SAR) for the detection of placed atop soil targets at first, and then, buried in soil targets. The aim is to use lower frequencies for penetrating foliage, vegetation, soil and ultra wide band for high resolution SAR image. This study comes after a precedent work which was the realization of a low frequency Radar Cross Section (RCS) measurement facility in the time domain[1]. This facility is funded by the DGA to meet CELAR requirement[2].

First results will be presented about lied on soil targets.

MEASUREMENT FACILITY

The measurement configuration is an UWB (100 MHz - 1 GHz) transmission and reception system implanted on a mobile boom. This boom which can reach about ten meters high, is installed on a truck and moves sideways along the test area. The system is presented on figure 1 and figure 2.

The general synchronisation is carried out by a sequencer. This device is remote by a coder wheel behind the truck which defines measurement step in azimuth along the moving direction.

A receiving system between receiving antenna and the digital sampling oscilloscope, is needed to protect the oscilloscope input from high level tension and to optimise the measurement dynamic. The effective signal is insulated by time windows. The receiving

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system gain is programmable from -20 dB to 40 dB in 1 dB step. This receiving system has got a limited frequency bandwidth. As a matter of fact, its bandwidth is 700 MHz at - 3 dB but it will be upgraded with better components.

The oscilloscope must acquire measurements during the moving with the best bandwidth in monopulse mode. It's the Lecroy LC 584 which was chosen for his adequate data transfer rate (GBIP): until 1 Mpoints at 280 Ko/sec. But its bandwidth is DC - 1 GHz (risetime ~ 350 ps) with a 8 Gsample/s rate and a 8 bit dynamic.

A tachometer is installed on the area test to provide the position of a near antenna fixed theodolite. This device is a Total Positioning System from Leica Geosystem. It is used in motion compensation to estimate the antenna phase centre position at each acquisition. Then, it is needed to calculate radar distance between pixel and antennas.

All the data are sent to a PC recording Unit for storage and data processing is subsequently done with Unix workstation.

Figure 1. Measurement facility

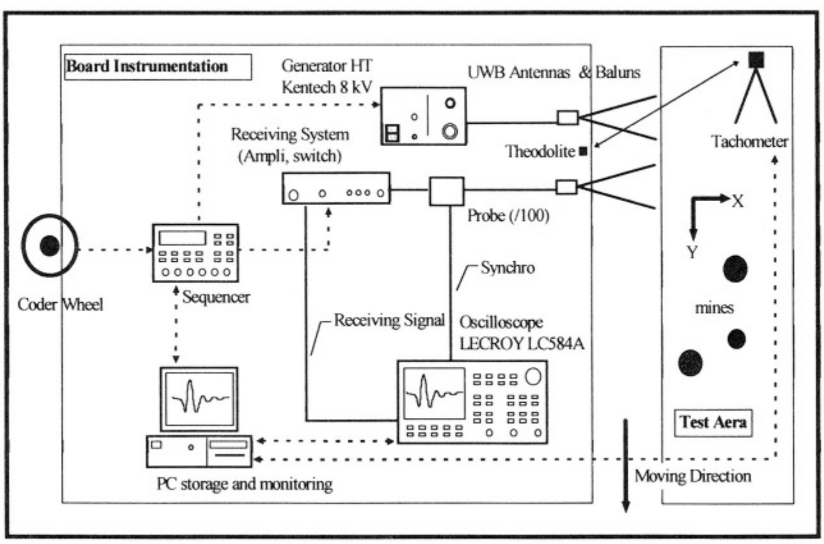

Figure 2. measurement facility synoptic

Pulse Generator

The generator used is a KENTECH generator based on a PBG3 which has a pulse output voltage of 8 kV, a 10 -90 % risetime better than 120 ps and a 50 % pulse duration (full-width at half-maximum) better than 460 ps. This pulse has a frequency range from DC to about 2 GHz (at -20 dB). See below on figure 3.

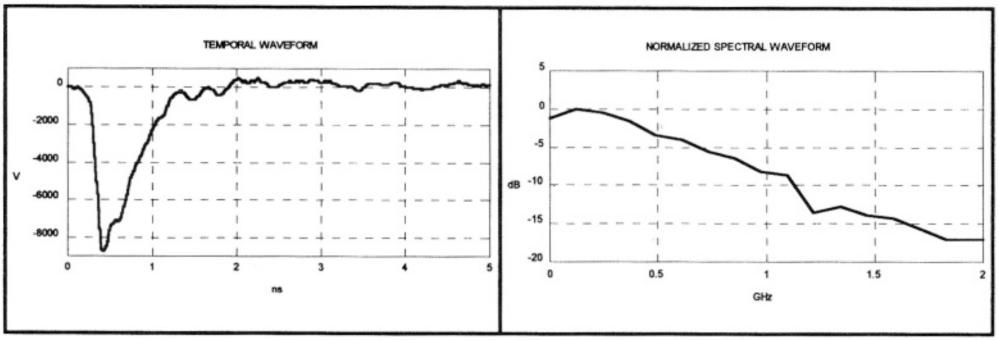

Figure 3. Generator pulse measurement

Antennas

Two identical antennas are used. The dimensions (less than a 60 cm ridge cube) are limited by the mechanical structure of the boom. The choice of the study was to design a 2D antenna to reduce weight and volume. That is why, antennas will be more directive in the antenna arm plan. The dimensions are also 1 m by 0.6 m. Two types of antennas have been selected : "Vivaldi" and "Scissors"[3] (see figure 4). Antennas are resistively loaded on the upper half-length of each arm to match impedance in low frequencies, and to limit back scattered field. Only a pair of "Scissors" antennas are currently used in measurements.

"Vivaldi" Antenna "Scissors" Antennas

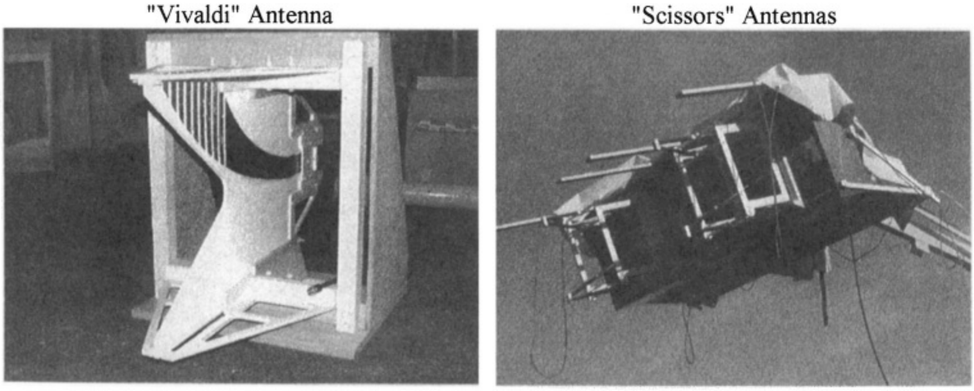

Figure 4. 100 MHz - 1 GHz UWB Antennas

The "scissors" antennas have been designed with the space time integral equation method. The computed radiated pulse is shown on figure 5. A differential coaxial balun[4] has been designed to feed correctly the antenna. The purpose is to make a transition between a 50 Ω coaxial cable and the 200 Ω two wire feed line and, to feed symmetrically the antenna.

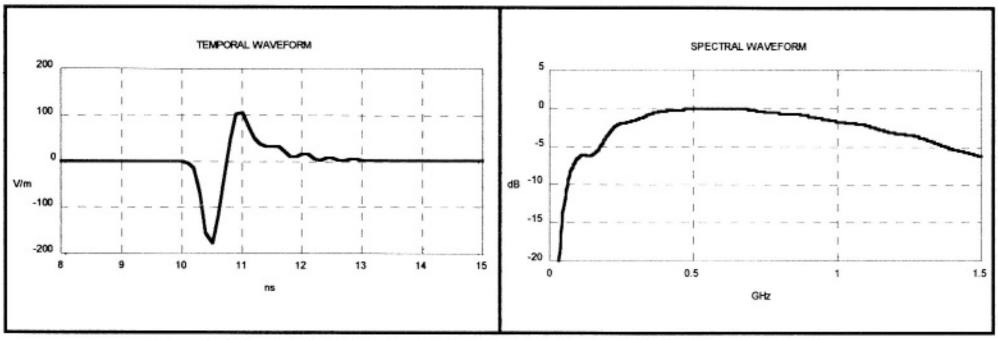

Figure 5. Simulated radiated pulse in the axial direction for "scissors antenna"

MEASUREMENT CONFIGURATION

A theoretical study enables to estimate the influence of the α site angle (from horizontal) on the maximum level scattered field by a buried target for normal and parallel polarisation. The scattered electric field has been calculated with a 2D FDTD method and a plane wave excitation. Dry, fairly wet and wet soil are considered with Debye model[5]. The normal incidence is the most favourable in free space but with a soil, the specular soil echo is very high and the target response is mixed with this soil echo. The maximum field level globally decreases if the site angle also decreases at a constant radar distance configuration (15 m). This phenomena is less important in case of wet soil for the parallel polarisation. Then, it is better to work with an site angle greater than 30°. Thanks to facilities of this Radar, the first measurements had been done at 8 meter high with targets lied on soil at 6 m α site angle ~50°), 10m (α~40°) and 17 m (α~25°) from the truck. Antennas are oriented in VV polarisation.

Another study is needed to know the radar displacement L length to collect the most of scattered information from the target for SAR data processing. This distance L depends on the position of the target, the nature of target and the antenna radiation. But, in worse case, the radar and the target may have omnidirectionnal characteristics. The punctual target M is supposed to diffract a pulse as a Dirac pick in order to estimate the received scattered field level v(y) at each position y (see figure 6).

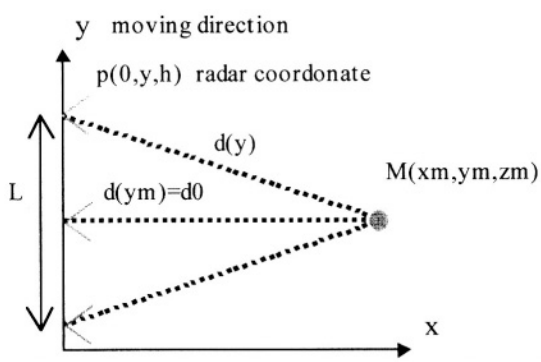

Figure 6. Radar distance between antenna and target

The radar distance between target and radar is $d(y) = \sqrt{d0^2 + (y_m - y)^2}$ with d0 the shortest distance between radar and target $d0 = \sqrt{x_m^{\ 2} + (z_m - h)^2}$.
If the attenuation distance is only taken into consideration, the electric field level can be expressed by:
$v(y) = \left[\dfrac{d0}{d(y)}\right]^2$, the maximum level is measured when the radar is in front of the target and it is normalised, so $v(ym) = 1$.

The SAR data processing used is based on coherently summing pulse responses *Sr* measured along the area test[4]. For a pixel *I(xi,yi)*, the algorithm identifies the sample *Sr(d)* corresponding to the radar distance (radar to pixel) for each measurement *Sr(p)* and sum them.

$$I(x_i, y_i) = \sum_{k=1}^{pos\_ant} S_r(d(x_i, y_i), p_k) \quad (1)$$

For a punctual target M(xm,ym,zm), an analytic approach is presented for calculating the pixel level I(xm,ym) corresponding to the target M :

$$I = \int_{y1}^{y2} v(y)dy$$ with $y1 < y2$ y1 start position and y2 end position of radar

With this variable change, $Y = \dfrac{ym - y}{d0}$, the M pixel image of the M point is :

$$I = d0 \cdot \left[\arctan(Y2) - \arctan(Y1)\right] \quad (2)$$

If the radar moves symmetrically along the target on the length L (see figure 6.), then the pixel level I_L is:

$$I_L = 2 \cdot d0 \cdot \tan^{-1}\left(\frac{L}{2.d0}\right) \quad (3)$$

In case of the radar displacement is very longer than the shortest radar distance d0, the level pixel should reach : $I_\infty = d0 \cdot \pi$.
The L distance to get K percent of the maximum pixel level I_∞ is :

$$L = 2 \cdot d0 \cdot \tan\left[\frac{\pi}{2} \cdot K\right] \text{ with } K = \frac{I_L}{I_\infty} \quad (4)$$

This result shows that if the radar covers twice the shortest distance (d0) between radar and target, the calculated pixel level is half of the maximum level I_∞. In configuration measurements described before, furthest targets are at the distance (d0) of 19 m. The radar moves on the length L of 90 m, so 75 % of information is collected for the furthest target (see figure 7).

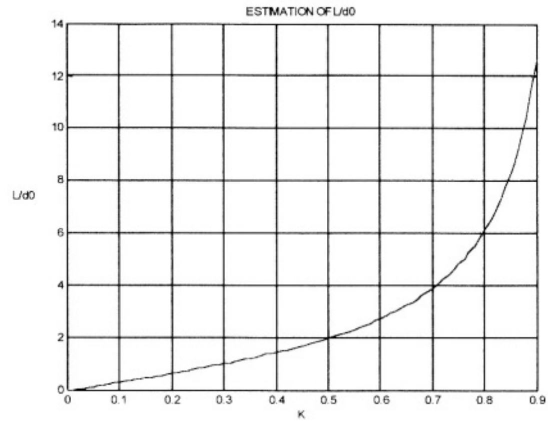

Figure 7. Estimation of the radar moving length

The radar resolution can be estimated with classical SAR expressions. The distance resolution Δx depends on τ width impulse and α incidence angle.

$$\Delta x = \frac{c \cdot \tau}{2 \cdot \cos\alpha} \text{ with } c = 3e8\ m/s. \tag{5}$$

In the measurement configuration, the distance resolution Δx is about 20 cm ($\tau = 1$ ns et $\alpha = 40°$). Once proceeded, theoretical signals have been computed to estimate the azimuth resolution Δy. The coherently summing treatment allows a good azimuth resolution Δy which is about 20 cm and depends on width impulse.

EXPERIMENTAL RESULTS

First measurements have been realised outdoor on January 2000. The test area was grass and the humidity soil rate was high about 30 %. More, roughness and homogeneity were not controlled because of some hole, mole-hill and little water puddle on soil surface. So, measurement conditions were realistic but rather unfavourable for target detection.

Several target types have been measured but two types are presented. Nine trihedrons were lied on soil at three distances (x = 6m, 10 m and 17m) with three different length ridges (22 cm, 30 cm, 49 cm). And, three metallic mines which are 11 cm high and a 27 cm diameter large were lied on mown grass. There are also false targets like mole-hill around mines. The scene is presented on figure 7.

Measurements show a high low frequency signal (less than 250 MHz). This is repeatable on each position measurements. It means that this signal may be the coupling signal between antennas and soil clutter. This undesirable information will be attenuated by filtering signal with a high pass numerical filter and by subtracting background. After, the coherently summing is proceeded with the correction of the distance attenuation.

The trihedron images are accurate and shows the correct position of targets due to motion compensation system (see figure 8). A zone between 5 m and 12 m (along distance x) seems to be more perturbed by soil clutter. The effective signal has been insulated by time window. No signal has been acquired before the distance on soil of x = 6 m. So, noise does not appear highly in nearby zone image (x < 5 m). For further zone (x > 12 m), clutter is less important if the angle site is lower than 40°.

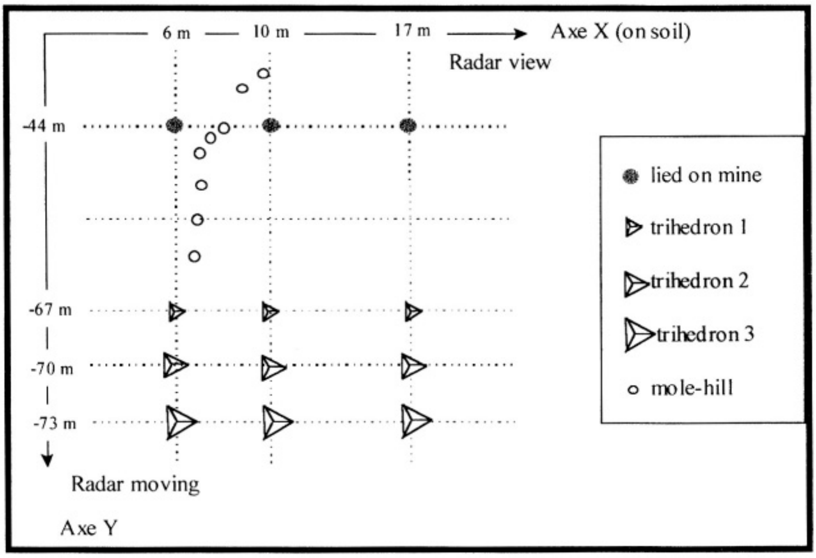

Figure 7. Test area description

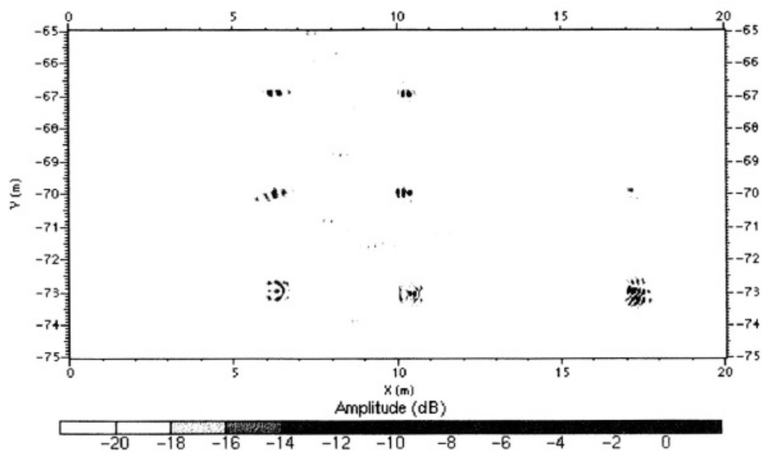

Figure 8. Trihedron image

The metallic mine image is encouraging. Lied on mines (y = -44m) are detected as well as mole-hills which can be considered like half conductive sphere lied on the soil because of the very high humidity rate (see figure 9). With theses smaller targets, the azimuth and distance can be estimated about 20 cm from mine image on figure 9. Signature on image presents side lobes along the distance axe. It can be explained by the temporal wave form target response and by the high pass filtering operation. But theses side lobes can be a criterion to distinguish small target from noise on image.

Theses first results show that contrast environment and permittivity discontinuities are detected.

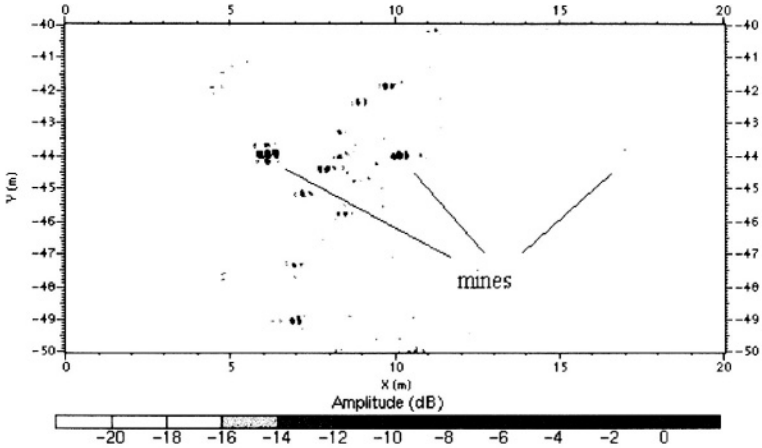

Figure 9. Mine image

CONCLUSION

This paper presents the first results obtained in rather unfavourable measurement condition with some metallic targets as trihedron and mine. Lied on soil targets are detected and good localised although roughness soil clearly appears on image. Theses results are encouraging and the next step of works can be decomposed on three points.

Data processing is based on coherently summing of measurements and it will be improved with radio frequency interference rejection, specific treatments for rejecting soil clutter and coupling, calibration with a canonical target. Sub banding image will be tested to reduce soil clutter and to discriminate target.

Then, some special measurement configurations will allow to analyse and reduce high coupling signal between antennas, truck and soil. The resolution will be estimated. The bandwidth of receiving system will be upgraded.

And more exhaustive measurements are planed with more favourable conditions, different type of soil and real mines. Targets will be buried. Results will be analysed and compared to FDTD simulations.

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