Design of Radars to detect the water flow and presence of water reservoirs inside the Earth

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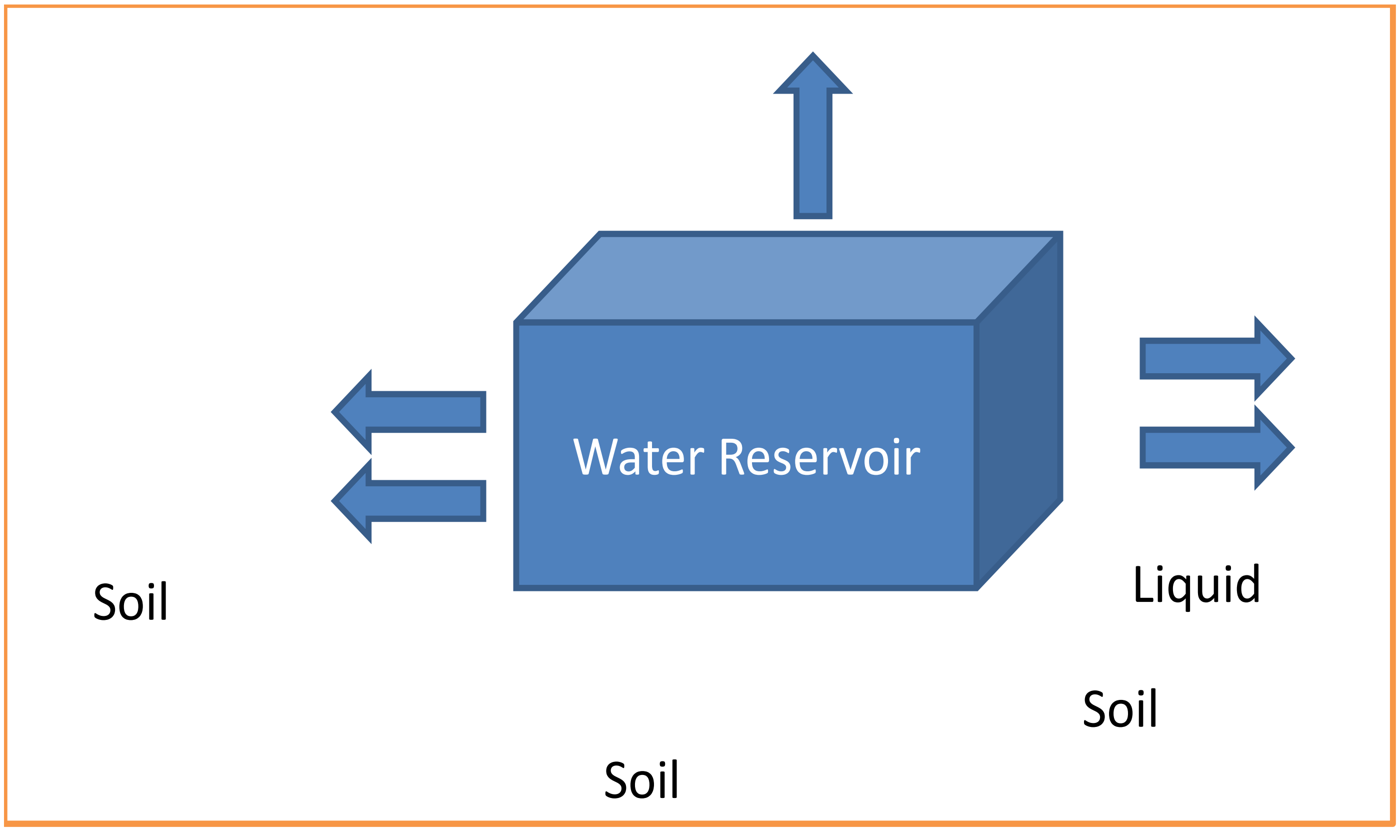
Radar Basic Requirements

- Estimate the water flow speed inside the Earth medium near a water pool during its discharge.
- Measure the existence of Water Reservoirs inside the Earth at large depths (15-25 meters).
- The two requirements being of different type two independent radars were designed, constructed and tested.

Measure Water Flow Speed inside the Earth during the discharge of a Pool



In principle a volumetric water flow measurement is needed. Taking into account the three dimensional distribution of water flow leaking out of the water reservoir being on the earth surface and assuming some symmetry along the vertical to the ground axis, the flow speed can only be measured in average terms. Based on past experience of our project team of the “Leaky” project the expected flow speeds are of the order of 1-10cm/sec depending on the soil type. Taking into account the gravitation force on the water and the initial speed vector of water flow at the interface of the reservoir and earth medium it is argued that measurement of flow vector in two projections will be sufficient to estimate the average water flow speed. The desired flow speed resolution is desired to be of the order of 2cm/sec.

Doppler Phenomenon

- When the radar signals are reflected by a moving medium we have a change of the phase of the two way propagating signal. This us expressed as frequency shift in a Fourier transform of the received signal.

- The Doppler shift is

$$\frac{\quad}{\sqrt{\quad}}$$

v = the average water flow speed

εr ~ 4 (relative dielectric constant of earth)

c = 3*108 m/s

(speed of electromagnetic waves in vacuum).

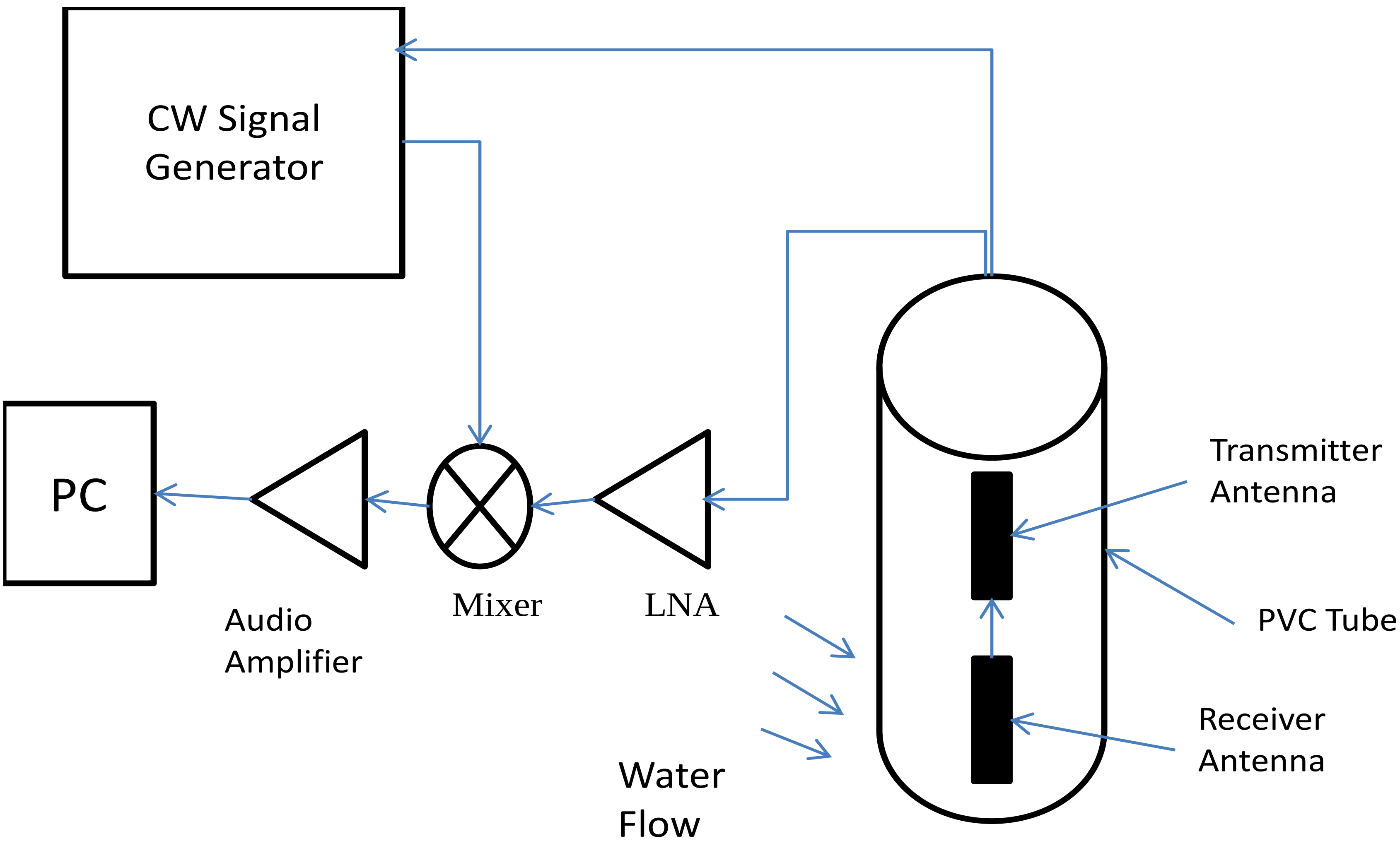
fo = 800 MHz carrier frequency

Placing the numbers:

- fd = 10.3v(Hz) and v ~ 1-10 cm/sec we obtain fd=0.10÷1.03 Hz

This shows that sensor a should be able to measure signals in the band 0.1 ÷ 1.0 Hz. This means also that the measurement process will need quite long time of the order of 1-10 sec. The target volume within which the water flow is taking place being quite close to sensor, it is expected that within sufficient receiver sensitivity the detection of water flow rate will be measured with sufficient accuracy.

CW Radar Block Diagram



CW Radar Antenna

Pulsed Radar

Based on the stated requirements a pulsed ground penetrating radar is designed having a relatively long pulse width (10nsec) as compared to conventional GPR's using 1nsec pulse widths. In order to achieve a good penetration to earth medium as much as possible low frequencies needs to be radiated towards the earth medium. However the lowest frequencies to be radiated towards the earth are limited because of the practical antenna size. We consider an antenna of the linear size of 3.0m is feasible to be used in practical terms, which corresponds to a low frequency of approximately 40MHz.

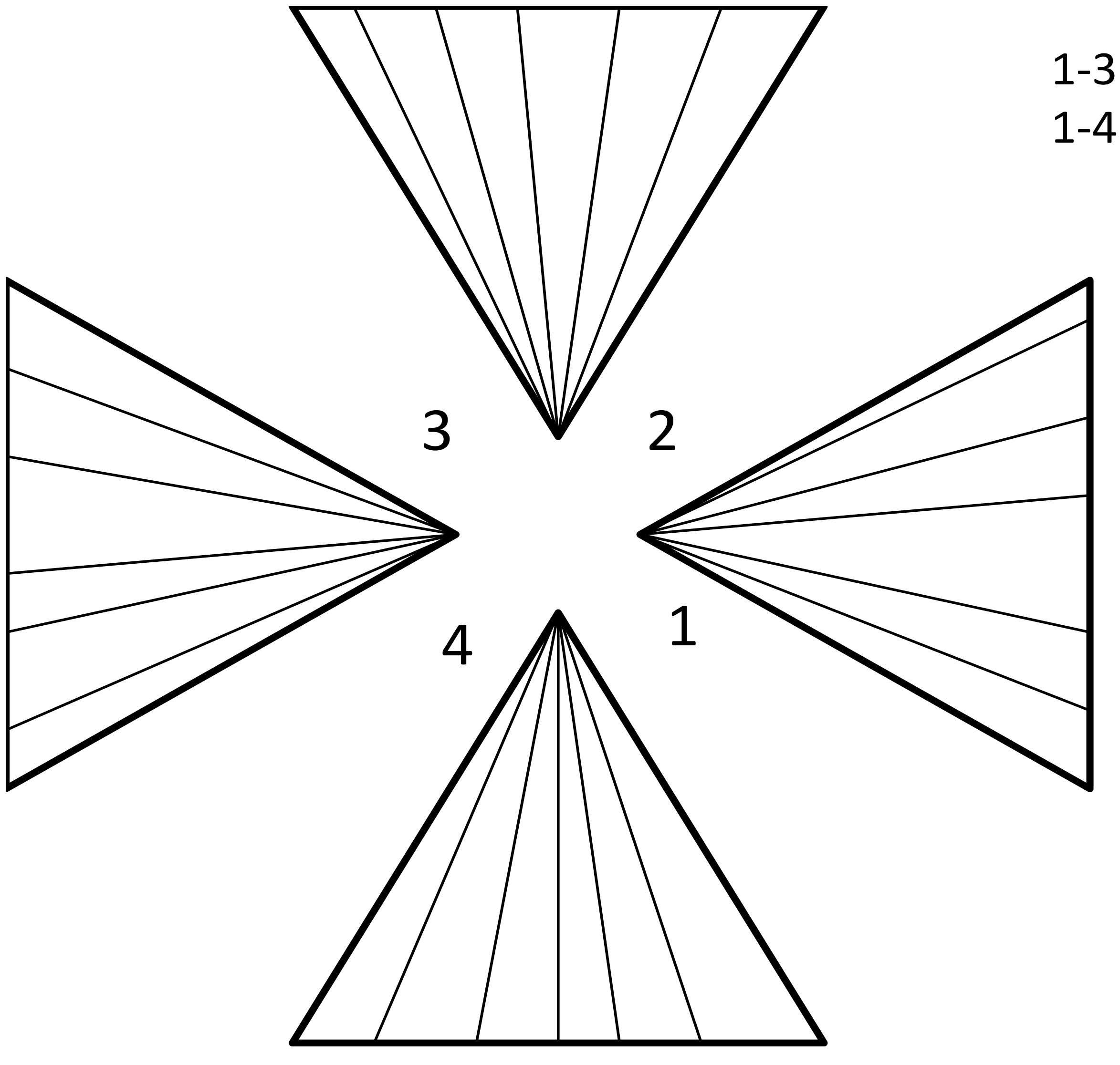
Being the pulse width 10nsec the higher frequency will be approximately of 100MHZ which corresponds to an occupied band by FM transmitters. Furthermore in order to achieve as much as possible high penetration depth a significant power level radiated towards the earth is sought. Assuming a pulse voltage of 100Volt at a 50Ω antenna load and a 25% radiation efficiency we shall have 10000/50*0.25=50W radiated power while the antenna gain is assumed to be near to 1.

- Assuming the worse ground conductivity (high) σ= 10-2 S/m, the attenuation at 50MHz radiation frequency will be 0.46 Neper/m or equally 4dB/m. Assuming a depth of 20m the total path attenuation will be L=160dB. The transmitted power being 50W or 47dBm, the received power will be -113dBm. The receiver sensitivity will be S= KTBNf , were K=1.38*10-23 J/K, B=50MHz (system bandwidth), Nf=6dB(noise figure) we obtain the sensitivity :

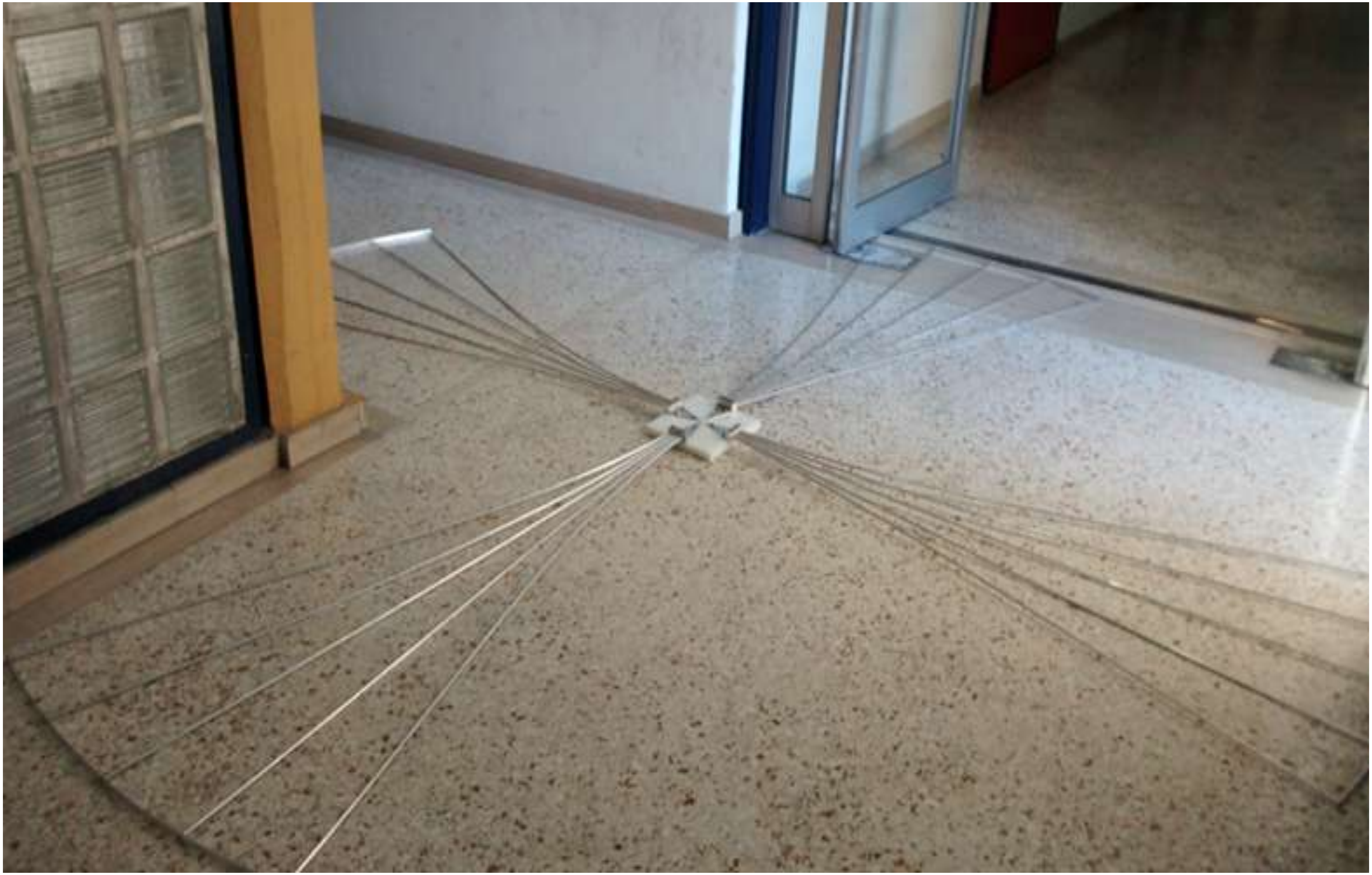
- S= -174(dBm)+77+6=-91dBm which shows the limitation of detection capability when the soil is very humid (σ=10-2 S/m).

- In case of the normal humidity such as σ=10-3 S/m the attenuation is 0.046 Neper/m or 0.4 dB/m and for a 20m depth the total path loss will be L=16Db which provide a total return signal power of: +16dBm which shows the sensitivity of system operation to ground conductivity.
- Taking into account the above figures the selection of transmitted power level is justified.

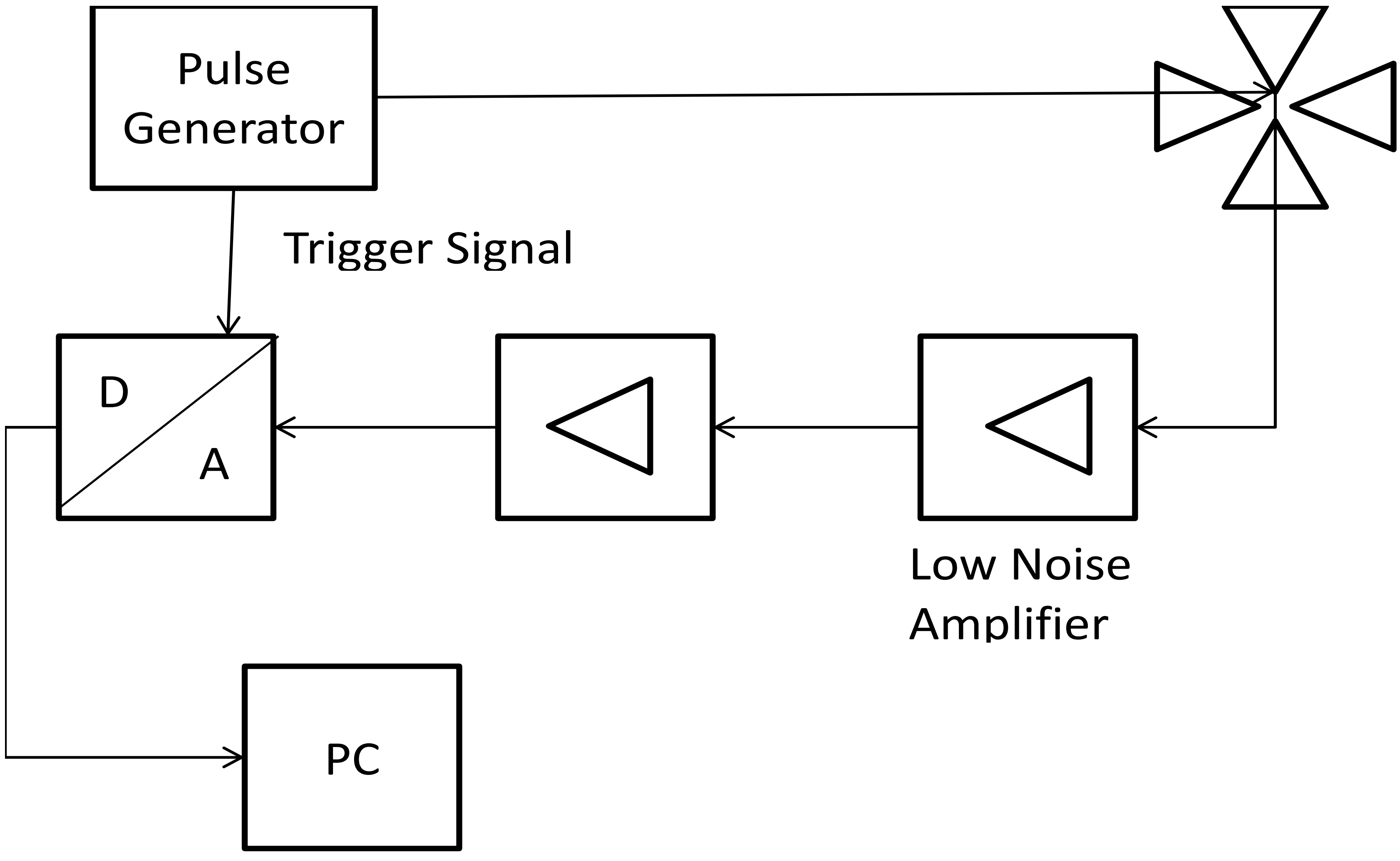
Antenna System

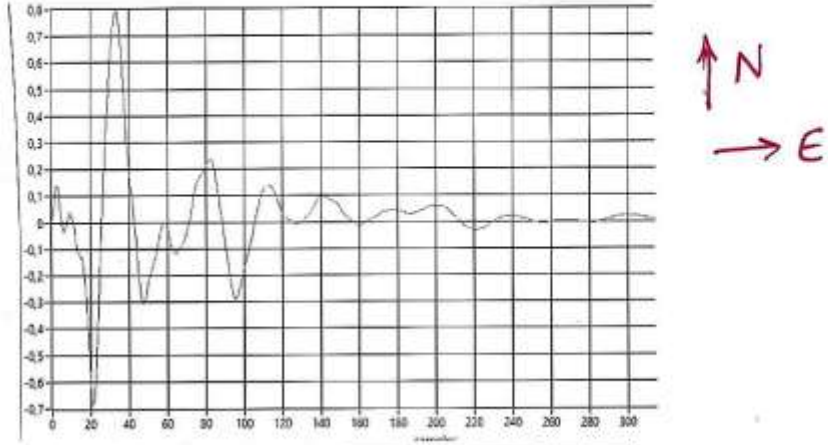


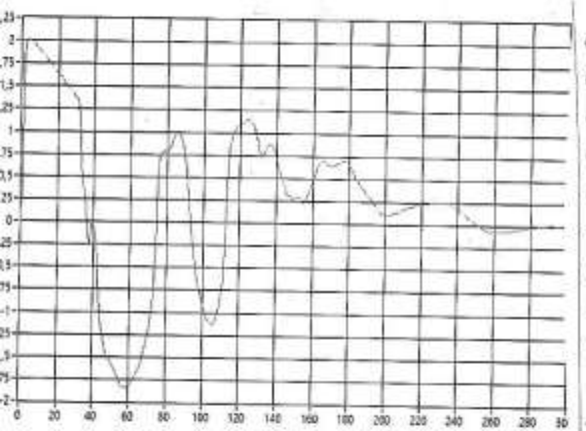
1-3 Receiver
1-4 Transmitter

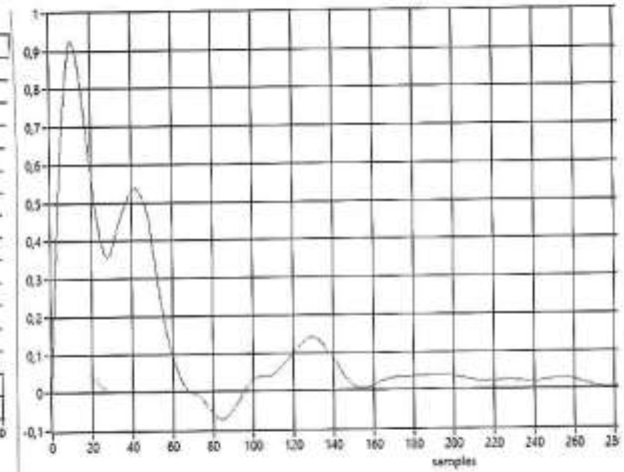


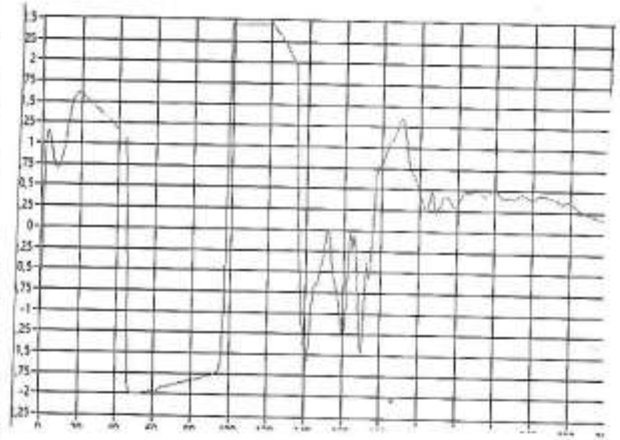
Block Diagram of the Pulsed Radar

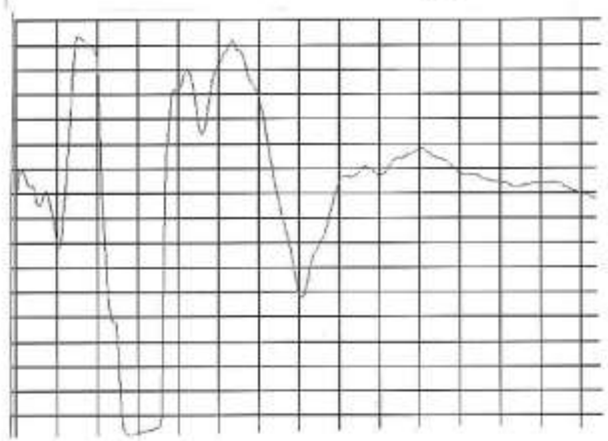












Sample	
50	3.75 m
100	7.50 m
150	11,25 m
200	15,00 m

$\varepsilon_r = 4$