# APPENDIX - I

# METHODS OF GPR DATA ACQUISITION AND PROCESSING

## DATA ACQUISITION:-

**Common-offset gather:** The collection of repeated measurements in stacked form along a survey line is known as Common-offset measurement. The Common-offset GPR profiling is commonly used for geological applications to map the continuity of the features at depth. Generally, GPR is used in a common-offset configuration to detect subsurface anomalies and to delineate the lateral and vertical changes in subsurface. The source and receiver antennas are separated by a fixed distance, and measurements are carried out by gradually shifting the antennas over the points with common-offset distance (Figure 5.6a). But in the perpendicular-broadside configuration the transmitter and receiver dipoles are placed perpendicular to each other. This method is fast and therefore relatively cheap, but a major drawback can be the lack of wave speed inFormation of the subsurface. However, when an object having contrasting electrical properties is present in the subsurface, a hyperbolic reflection occurs in the GPR data. From this hyperbola, the wave speed in the subsurface can be estimated as described in van der Kruk and Slob (1999).

**Common-mid point (CMP):** Common-mid point (CMP) method is a GPR technique to estimate the subsurface velocity structure of the study area. It is generally used to analyze the variable velocity and density layers of the shallow subsurface (Huisman et al., 2003; Jol and Bristow 2003). The CMP profiles are acquired in point mode, where the orientation of the antennas is perpendicular to the electric field polarization. The measurements are taken by manually shifting to transmitter and receiver from a mid point to opposite directions up to a maximum distance. According to Jol and Bristow (2003) the shifting of the antennas should be continuing until there is no return from the subsurface. In this technique the high pulses of EM energy are radiated downward at every shooting point and the receiver records the signals in stacked form. The stacking of the signals facilitates to reduce the signal to noise ratio. In the CMP mode the transmitted EM waves repeatedly travel through same material but the offset distance between the antennas are changed (Figure 5.6b). The CMP sounding is a plot between antennas separation (offset distance between antennas) and two way travel time. The strongest reflections at the top of the data are the direct air waves and the direct ground waves. The CMP data can identified from the alignment of these two reflections which represent to direct propagation of radar waves from transmitter to receiver through air and top skin of the ground (Neal, 2004). Together with the expressions of the ground wave, valuable inFormation about the properties of the subsurface can be obtained. The velocity structure of the study area can be determined by CMP method (Yilmaz, 2001). The calculated velocity obtained by this method is used to convert the time window into the depth scale and in advanced GPR data processing (Yilmaz, 2001; Huisman et al., 2003). Use of CMP method in the present study indicate that the velocity sounding should be essentially carrying out at each survey site and if possible several test profiles should be processed prior to final acquisition.

**Wide-angle-reflection-refraction (WARR):** This is the Common source method in which the transmitter is fixed and the receiver is gradually shifted opposite to source with common step size. The common receiver method allows shifting of the position of transmitter away from stable receiver antenna (Figure 5.6c, d). The Common source and Common receiver methods of GPR data collection are also known as wide-angle-reflection-refraction (WARR) technique and is generally used to make out the penetration speed (velocity) of the radar waves. This technique is generally used in the areas having rugged topography, because it is quite easy to place an antenna at fixed position and shifting to other along a line at discrete points. The acquisition fundamentals of this technique are similar to the previously described CMP method.

**High-resolution 3D GPR surveying:** Three-dimensional GPR surveying is complex but an interesting method to recognize the shallow subsurface geological setup. From a three-dimensional measurement, the vertical and lateral dimensions of buried object or structure present in the subsurface may be made visible. 3D GPR technique is highly acceptable in engineering applications where regular monitoring of structural integrity needs nondestructive cost effective technique (Daniels, 2000). Three-dimensional displays have an advantage of looking at the entire survey site at once. It allows the creation of plan views at different depths as well as perspective views by cutting the 3D solid cube in slices (Patidar et al., 2006). Delicate features that are easily missed or misidentified in 2D radar profile can be readily detected by 3D GPR survey. Three-dimensional display has important compensation for applications that require recognition of linear feature. Identifying pipes, cables or structural elements in soil or concrete becomes an easier task when they appear as continuous lines in a 3D display (RADAN for windows, 2000). To obtain a three-dimensional image of the subsurface, numerous measurements are carried out along parallel survey lines to record reflected and diffracted electromagnetic waves (Figure A.1).

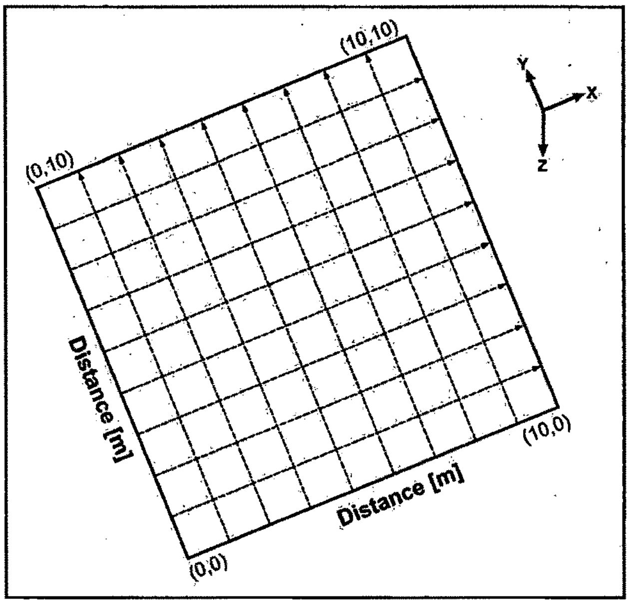


**Figure A.1** The survey planning for 3D GPR data acquisition.

The software used for 3D GPR data processing interpolate the 2D parallel profiles into the systematic format to create the 3D solid cube. In practice, several parallel survey lines are measured with common offset present between the source and receiver antenna. This offset should be same for inline (parallel to the survey line) and crossline directions (perpendicular to the survey line). The quality and resolution of 3D GPR data depends upon the grid layout, sampling and scanning speed of the antenna and the electromagnetic properties of the surveying medium (Daniels, 2000). The accuracy of 3D GPR data increases as the number of profiles increases and the distance between consecutive profiles decreases. To collect the high resolution 3D

GPR data one should raise profiles along two perpendicular directions, which allow sufficient data to generate high resolution 3D cube of the survey area. The number of transects in inline and crossline directions should be target oriented but the antenna frequency, volume of the survey area and field conditions are also restrict the survey (Beres et al., 2000; Green et al., 2003). When the 3D grid lines are situated over the undulated terrain, surface normalization operation should be performed prior to data interpretation. This means the sampling interval should not be too sparse, resulting in loss of inFormation. In time and space, the measured samples must satisfy the temporal sampling and spatial sampling criterion, respectively. Accurate positioning of sets of profiles, selection of viewing angle, combination of frequency cutoff filters, thickness of time slice and suitable colour range are some important criterions to be followed during data analysis (Young and Sun, 1998).

PROCESSING:-

**Conversion of the data in a usable digital format:** In the survey carried out by Benson 1995, the data was both plotted and record on a magnetic tape device for use on a computer. But recently manufactured GPR units automatically recorded the data in digital format. Data collected by GPR unit can be uploaded to computers for post survey data processing using various geophysical softwares. Some of the GPR units are sophisticated enough to allow processing and printing the data while still in the field (Jol and Bristow, 2003). There are lots of different file formats to work with, and these days varieties of utility programs are available for converting different file formats. It is an initial task to convert the available data in usable format. The background inFormation regarding the GPR data acquisition parameters, profiling method, general geological setup of the area and other technical details of the surveying terrain is important and should be collected and store properly with acquisition notes (Jol and Bristow, 2003).

**Removal or minimization of direct air and ground waves from the data:** Many times, there are large reflection amplitudes at the interface between air and soil surface immediately below the GPR antennas. The high contrast between the air and soil conductivities can create direct air and ground waves that may mask reflections from important objects just below the subsurface. These direct air and ground waves can be removed by computing the time of arrival and wavelength, then by subtracting the theoretical wave of the wavelength from the actual wave in each GPR trace (Yilmaz, 2001). In many cases these waves are not removed since they do not disturb the interpretation of the GPR data and the reflection strength of the direct ground waves is used to compute the surface soil moisture (Davis and Annan, 1989; Lunt, 2005).

**Reduction of unwanted reflections (noise) from above surface objects:** During a GPR survey, special attention must be paid to objects which are present above the earth's surface. As already discussed, above that elementary dipole antennas emit electromagnetic waves into the air as well (Jol, 1995). When an electrical contrast is present in the air, a reflected wave occurs and can be recorded by the receiver antenna. Due to the low losses in air and the high wave speed, these reflected waves can obscure the data and can make the interpretation of GPR data a difficult task. Especially in an urban area it is important to know the origin of these reflections and how to reduce the influence of these unwanted reflections. In practice, this signal emission into air can be reduced by shielding the antennas (RADAN for windows, 2000). However, the physical size and portability considerations generally limit the shield effectiveness for low frequencies. But the erroneous interpretations are still made, which demonstrates that the recognition of these unwanted reflections is mainly based on experience. To identify a diffractor present above the surface, like a tree, is quite easy. The reflections will result in a hyperbolic event with a much smaller slope compared with reflections coming from the subsurface (Yilmaz, 2001). Another option to remove reflections of above-surface events is to flatten the scattered event by applying the low-pass filter (Sun and Young, 1995). More difficult is the recognization of the reflections coming from larger objects present above the surface and parallel to the survey line. These reflections will result in sub-horizontal events, which are difficult to identify (Kruk and Slob, 2004). For these types of reflection a combined common-offset and common-mid point analysis has to be carried out. It is shown that the presence of the soil leads to relatively strong reflections from vertical objects, which are present in a specific plane relative to the antennas. The unwanted reflections from a vertical object (tree) can be reduced by choosing proper orientation of the source and receiver antennas because the electric field polarizations play an important role in data acquisition. The largest reflections occur when the polarization of the electric field is parallel to the object causing the reflection. To reduce the unwanted above surface reflections, the antenna configuration should be chosen such that the emitted electric field is polarized perpendicular to the objects which are present along the survey line (Figure 5.5). Vertical objects should be present in the H-plane and horizontal objects should be present in the E-plane of the source and receiver antennas to minimize the effect of unwanted reflections in GPR data (Davis and Annan, 1989; Daniels, 2000). In reality, the top soil is often different then the soil present deeper in the subsurface due to recent precipitation. To prevent erroneous interpretations, the acquisition parameters of a field survey can be altered to reduce the recording of unwanted reflections. The interpreter should keep in mind that reflections coming from objects above the surface can be present in the data. The basic consciousness regarding surveying facilitates is necessary to identify unwanted reflectors in GPR data.

**Amplitude and Gain adjustments to the data:** The powerful EM signals burst by source antenna (transmitter) to the subsurface encounter with layers of high conductive material and the amount of energy is attenuated (Jol, 1995). In this condition receiver may have lower reflection amplitude. This may be due to the battery (external unit) of GPR system that may wear down as survey progresses. This results in GPR traces with lower and lower reflection amplitudes during the survey (Yilmaz, 2001). Determining the battery power loss over time, then multiplying each trace by a constant value to recover these losses can correct this problem. Attenuation of the GPR signals is also depends on the dielectric conductivity of the examining substances (Davis and Annan, 1989). It can be corrected by applying gain adjustments of each trace. To correct the spherical dispersion and enhance the quality of radar signals, automatic gain control (AGC) function is applied. AGC function computes the signal amplitude of individual trace over a time window and amplified to signal with average point (Annan, 1999). Several methods are available to compute the attenuation and enhance the gain to improve the quality of the lower reflection amplitudes.

**Static adjustments to the data:** As discussed earlier that in initial stage of the GPR data processing some static corrections like, time-zero alteration and distance normalization are executed. But the elevation changes along a survey line are not taken into account when the GPR data is recorded on a time base. This can lead to significant distortion of the subsurface images if uncorrected (Fisher et al., 1996). This problem is made worse because the radiated energy from a transmitter always propagates outwards from the antenna at right angles to the surface (Neal, 2004). This can be corrected by moving the traces up and down by an appropriate two way travel time relative to a common datum and based on the knowledge of velocity. These adjustments remove the effects of elevation changes in GPR profile carried out over the undulated terrain. The topographic corrections require the repositioning of traces at their original place. Surface normalization operation shifted to traces along the time axis using GPS track profiles or field elevation graphs, which is necessary to calculate the accurate depth of subsurface feature and to interpret the sedimentary facies and structural discontinuities.

**Identification and processing of signal scattering:** The GPR profile is an array of traces registered by control unit against two-way travel time. The collected data is a time-history record of radar waves measured in nanoseconds. The output signal voltage peaks are plotted on the ground penetrating radar profile as different color bands by the digital control unit. The radar signal scattering is a common phenomenon occurs at the interface of subsurface mediums having different dielectric permittivity (Reppert et al., 2000). Basic understanding of the scattering pattern of EM waves is an important criterion to interpret the GPR profile (Chamyal et al., 2007). It can provide us vital inFormation about the subsurface stratigraphy and nature of buried objects. Daniels (2000) described four types of scattering: specular scattering, refraction scattering, diffraction scattering and resonant scattering.

When the downward radiated EM waves are reflected back from the interface of different dielectric permittivity and the angle of incidence is equal to the angle of reflection the phenomenon is known as specular scattering (Figure A.2a). It is common in bistatic GPR antenna arrangements, where the transmitter and receiver are the separate entities. The refraction scattering occurs in GPR data when some amount of radiated radar energy are reflected bake to the surface from the contrasting subsurface interfaces and the remaining energy propagates downward with different speed in the direction of diffraction (Figure A.2b). The angle of the diffraction depends on the contrast between the electrical properties of the propagation media and can be determined by Snell's law (Daniels, 2000). Diffraction scattering is a common phenomenon in the GPR profiles. If the object has higher electromagnetic conductivity than the host medium, then there is some bending of energy occur from a point and the waves are separated out in various directions (Figure A.2c). The nature

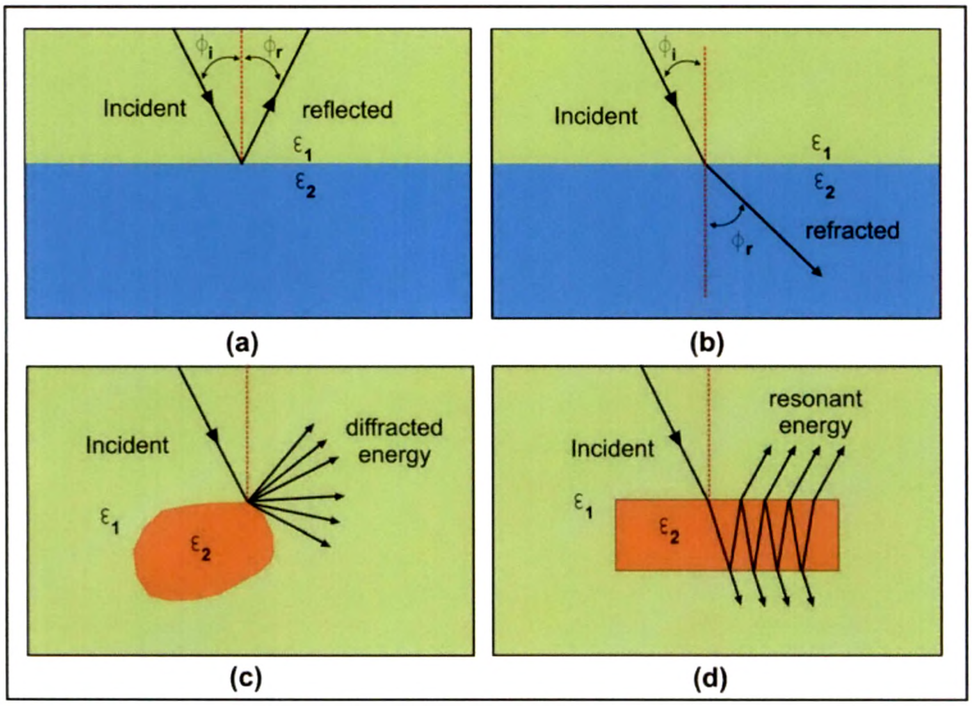


**Figure A.2** General scattering patterns for radar and seismic waves. (a) Specular scattering (b) Refraction scattering (c) Diffraction scattering (d) Resonant scattering (after Daniels, 2000).

of diffracted energy depends upon the shape of the object, wavelength of incident waves and the roughness of the interface boundaries (Daniels, 2000). The geological features like vertical fault plane, unconformity, lithological boundaries and abrupt facies changes generally diffract radar energy and appear in the GPR profile as semi-coherent energy pattern where the reflections splay out in different directions from a point (Daniels, 2000). Resonant scattering of the signals occurs when a layer or object of higher electromagnetic conductivity is sandwiched between the layers having relatively low electromagnetic conductivity (Figure A.2d). This is common in sedimentary terrains because of the occurrence of alternate layers of varying dielectric permittivity (Neal, 2004).

**Filtering of radar data:** To diminish the effects of unwanted signals, appropriate frequency filters are applied on raw GPR data. The purpose of filtering is to remove unwanted background noise. For example, if a cellular phone or power transmission line is located in the study area, it may create noise along the trace at a certain frequency. To remove these kinds of clutters, frequency spectrum is calculated and the time-domain trace data is converted to the frequency domain using the Fourier transform (Daniels, 2000). Desired frequencies are zeroed out and again the traces are converted back in the time domain using the inverse Fourier transform (Daniels, 2000). Filtering strategies can include band pass (removing frequencies in a certain range), low pass (removing low-frequency signals), and high pass filtering (removing high-frequency signals).

**Migration:** Migration is a procedure to convert diffracted GPR signals to their correct position (Olhoeft, 2000). According to Young and Sun (1998) the migration function is applied to rearrange the true position of steeply dipping subsurface reflections and hyperbolic diffractions. The goal of migration is to make the reflection profile look like the geological structure in the plane of the survey. Generally the buried metallic objects, boulders, strata of higher electric conductivity or overhead objects like; hi-tension electric lines, tress, mobiles phones and concrete structures scattered to radar signals and appear as a strong hyperbolic return in the GPR profiles. The shape of the hyperbola depends on the velocity of the reflected waves (Young and Sun, 1998). If these hyperbolas are caused by buried subsurface anomalies or gravel beds then one can measure the penetration speed (velocity) of the downward radiated radar waves. This technique can be used to calculate the accurate depth and geometry of the buried anomalies. But the hyperbola caused by external or overhead object may mask to original data and should be removed prior interpretation (Yilmaz, 2001).

There are many seismic migration techniques used in oil and gas industry. Some of them can be directly applied to GPR data when the similar assumptions arise (Neal, 2004). According to Yilmaz (2001) there are generally two types of migration, time migration and depth migration. Time migration is suitable in the areas having small to moderate lateral velocity variations where as depth migration required to have a true subsurface image of the area having large variations in lateral velocity.

**Deconvolution:** Deconvolution function is applied to eliminate the effect of ringing from GPR data (Todoeschuck et al., 1992). Multiple reflections "ringing" mask original radar reflections and cause misinterpretation of targets. Deconvolution is a systematic process for removing the effects of previous filtering processes resulting from propagation of a source wavelet through an inhomogeneous earth and the system ringing. The ringing multiples associated with water layers and weathered subsurface horizon can be wipeout by passing the data through deconvolution (Neal, 2004). But some workers believe that it is quite difficult procedure and some time does not show good results with radar data, although it may be useful where reverberation is a major problem. Neal (2004) suggest that care should be taken while performing deconvolution and perhaps not to use this as an essential processing step.