Geophysical Research Abstracts
Vol. 18, EGU2016-18097, 2016
EGU General Assembly 2016

State-of-the-art and trends of Ground-Penetrating Radar antenna arrays

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The aim of this contribution is to offer an overview on the antenna arrays for GPR systems, current trends and open issues.

Antennas are a critical hardware component of a radar system, dictating its performance in terms of capability to detect targets. Nevertheless, most of the research efforts in the Ground-Penetrating Radar (GPR) area focus on the use of this imaging technique in a plethora of different applications and on the improvement of modelling/inversion/processing techniques, whereas a limited number of studies deal with technological issues related to the design of novel systems, including the synthesis, optimisation and characterisation of advanced antennas. Even fewer are the research activities carried out to develop innovative antenna arrays.

GPR antennas operate in a strongly demanding environment and should satisfy a number of requirements, somehow unique and very different than those of conventional radar antennas. The same applies to GPR antenna arrays. The first requirement is an ultra-wide frequency band: the radar has to transmit and receive short-duration time-domain waveforms, in the order of a few nanoseconds, the time-duration of the emitted pulses being a trade-off between the desired radar resolution and penetration depth. Furthermore, GPR antennas should have a linear phase characteristic over the whole operational frequency range, predictable polarisation and gain. Due to the fact that a subsurface imaging system is essentially a short-range radar, the coupling between transmitting and receiving antennas has to be low and short in time. GPR antennas should have quick ring-down characteristics, in order to prevent masking of targets and guarantee a good resolution. The radiation patterns should ensure minimal interference with unwanted objects, usually present in the complex operational environment; to this aim, antennas should provide high directivity and concentrate the electromagnetic energy into a narrow solid angle. As GPR antennas work very close to the matter or even in contact with it, changes in electrical properties of the matter should not affect strongly the antenna performance, so that a wide applicability of the radar system can be achieved. Moreover, antennas should provide stable performance at different elevation levels. For an efficient coupling of electromagnetic waves into the ground/investigated structure, good impedance matching is necessary at the antenna/matter interface. Another important requirement concerns the weight and size of the antennas: for ease of utilisation and to allow a wide applicability, the antennas shall be light and compact.

Array of antennas can be used in GPR systems to enable a faster data collection by increasing the extension of investigated area per time unit. This can be a significant advantage in archaeological prospection, road and bridge inspection, mine detection, as well as in several other civil-engineering and geoscience applications where the collection of data requires the execution of a large number of profiles. Moreover, antenna arrays allow collecting multi-offset measurements simultaneously, thereby providing additional information for a more effective imaging and characterisation of the natural or manmade scenario under test. Two approaches are possible to GPR array design. The simplest and most common is to conceive the array as a multi-channel radar system composed of single-channel radars. Much more can be achieved, if array-design techniques are employed to synthesise the whole system. This second approach is just beginning in the GPR field and is definitely promising, as it gives the possibility to fully exploit the potentiality of arrays. Another important issue, when using GPR systems on irregular surfaces, is that the position of array elements has to be recorded during the surveys, by using suitable high-precision positioning systems. Current research activities on the design of GPR arrays are progressing in various directions, including the synthesis of arrays with a high directivity achieved by using simple elements, arrays with the capability of a steerable beam as in smart antennas, arrays composed of adaptive antennas with electronic control of characteristics to adapt to different soils and materials, and application-specific arrays.

Acknowledgement
This abstract is a contribution to COST (European COoperation in Science and Technology) Action TU1208 “Civil engineering applications of Ground Penetrating Radar” (www.GPRadar.eu). The Authors thank COST for funding the Action TU1208.