Testing the advantages of ultra-dense GPR antenna arrays for the Archaeological Prospection

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Introduction:
During the last few years, the use of Ground-Penetrating-Radar (GPR) multi-channel antenna arrays in the Archaeological Prospection increased dramatically. The main advantage of this type of survey is a much faster data acquisition combined with a dense profile spacing. However, most of the common multi-channel arrays consist of antennas with a spacing of not smaller than 8 cm. The aim of our test survey was to evaluate how an even denser spacing of 4 cm, that is provided by the IDS Stream-C GPR device at a centre frequency of 600 MHz, can improve the detection of faint archaeological features.

Test site:
As a test site, the Great Roman Bath of Kempten-*Cambodunum* was chosen. Kempten is located in the southwestern corner of Bavaria in a region called Allgäu, ca. 80 km southwest of Augsburg (Fig. 1).

Fig. 1: *Topographical map showing the location of Kempten (© Geobasis data: Bayerische Vermessungsverwaltung)*

From an archaeological point of view, *Cambodunum* was the first capital of the Roman province Rhaetia. It was founded in the first century AD and soon, most of the city was constructed as stone buildings.

One of the most prominent ones had been the Great Bath that covered an area of 4000 m² and hence belonged to the hugest complexes of this kind north of the Alps (Gottlieb & Weber, 1989; Weber, 2000). The reason for choosing this building as a GPR test site, is that several rooms still have partly preserved hypocaust pillars (Fig. 2), which are challenging to map with standard GPR devices.

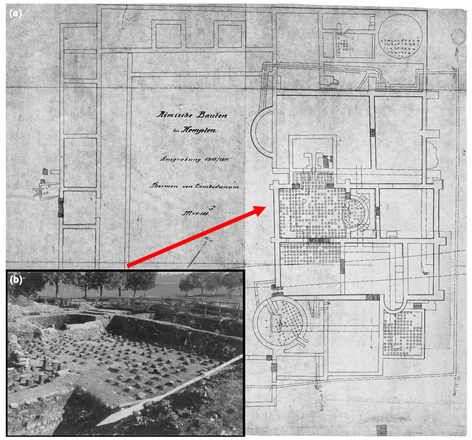

Fig. 2: *Map (a) and photo (b) of the excavated remains of the Great Roman Bath of Cambodunum showing the walls and the location of the hypocaust pillars. The excavation took place already in 1911 and was refilled afterwards.*

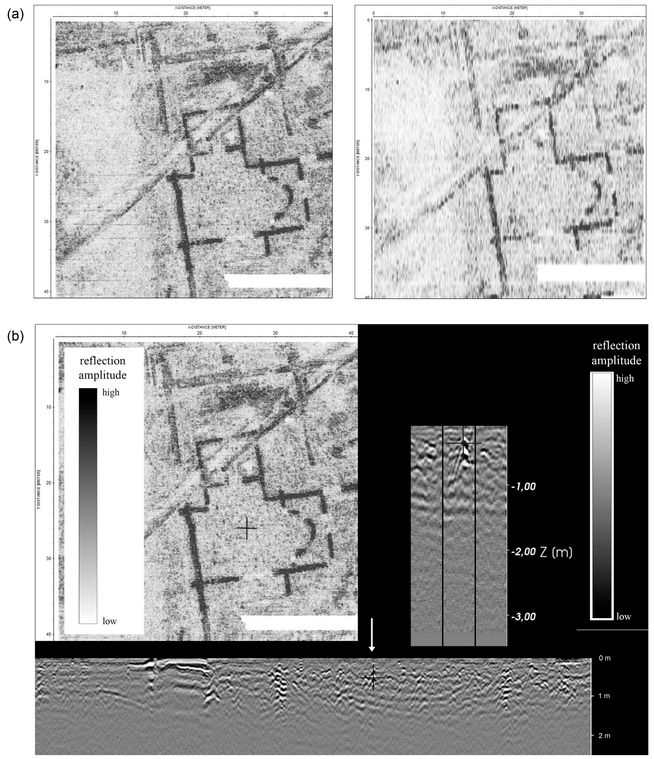

Fig. 5: *a) Comparison of the GPR depth slices of 10 cm thickness in 65-75 cm depth of the IDS Stream-C (left) and the IDS Duo (right). (b) A sample hypocaust picked in the 65-75 cm depth slice and the corresponding inline and crossline profiles.*

Survey results:
The test survey was executed on a 40 x 40 m grid covering the main part of the former Roman Bath house. The same area was measured simultaneously with the IDS Stream-C multichannel array and a standard single channel IDS Duo to compare the corresponding depth slices (Fig. 5a).

The Stream-C data shows a multitude of small hypocaust pillars with a lateral length of 25 cm (Fig. 5b). In total, around 22% of the former excavated pillars can be mapped in the GPR data. The reason for this, at a first glance, quite low value is that the hypocausts consisted of unstable layered bricks that collapsed during excavation or refill. Furthermore, the original excavation map also has some mistakes in the location of the pillars, as not all of them were exactly levelled and simply added in a regular raster. Such deviations of the real position of the archaeological remains and their mapped ones are also documented several times during modern excavations in *Cambodunum*. Nevertheless, more than 89% of the potential hypocaust pillars identified in the GPR data correspond to the excavation map. The remaining error is conditioned by the fact that in some cases, the GPR data simply shows bigger stones of the infill. The effect of the excavation's refilling with the digging can be seen in the shallower depth slices up to 50 cm below modern surface that show an extremely disturbed signature inside the building.

Looking at the single channel dataset of the IDS Duo, reveals that, for sure, the well preserved walls of the Roman Bath are visible too (Fig. 5a right). These features are not treated further, as they are already published comprehensively in Linck (2013). However, in this case only 3% of the hypocaust pillars can be identified in the corresponding depth slices. Hence, such small archaeological remains can only be mapped by ultra-dense GPR antenna arrays and will be missed by standard single antenna systems. In case of expected small-scale subsurface structures, the application of an antenna array is thus advisable.

Survey device IDS Stream-C:

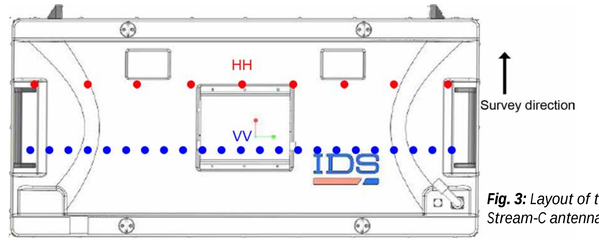

Fig. 3: *Layout of the IDS Stream-C antenna array.*

The IDS Stream-C multichannel array consists of 23 antenna dipoles in VV configuration that are 4.4 cm spaced and 9 HH dipoles with 10 cm spacing (Fig. 3). The antenna frequency is 600 MHz. Hence, the VV dipoles have a distance below the Nyquist interval and the corresponding data is fully 3D. Within one survey swath, a coverage of 96 cm can be achieved (Fig. 4). As the HH data does not show more information than the VV one due to the dense sample spacing, only the latter is presented here.

Fig. 4: *The IDS Stream-C array mounted onto a self-built sled in action at the test site in Kempten.*

References:
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