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**R. Zetik / J. Sachs / B. Schneegast**

# Non-Destructive Testing with Imaging Radar: First experience with a Laboratory Equipment

## I. INTRODUCTION

Surface penetrating radar (SPR) uses wideband electromagnetic waves, transmitted into a volume under test to find buried pipes, cables, other objects, and anomalies. Material inhomogenities, e.g. of concrete or other non-conductive construction materials can also be determined with this method. SPR measures the back scattered waves in lossy and dispersive embedding media in order to detect buried objects and to indicate their position and size. Nowadays, SPR is used in many non destructive explorations, such as geological prospecting or civil engineering. But there are still some inconveniences caused by unsatisfactory data acquisition and processing. Actually, the possibilities of the method are not fully used. Advancements in SPR technology mainly in civil engineering are expected in the following fields:

- improvement of ultra wideband radar electronics and antennas,
- using of antenna arrays with various antenna polarisations,
- exact local assignment of measured data,
- sophisticated multidimensional signal processing.

The exact relation between signals and positions is fundamental to use sophisticated higher dimensional software, that is aimed to create images which can be understood not only by radar specialists.

A flexible experimental imaging radar equipment with widely adjustable parameters is necessary to meet all needs of hardware and software development of new SPR components. Such a system was established at the Technical University of Ilmenau, department of Electronic Measurement Technology. It consists of a precise antenna positioning system and a network analyser HP8753D as stepped frequency radar. This equipment is intended:

- to test and develop radar antennas and arrays,
- to analyse different scanning procedures,
- to try new radar electronics,
- to keep practical experience in SPR Imaging,
- to accumulate scattering pattern of certain objects, and
- to verify signal processing algorithms.

## II. MECHANICAL CONSTRUCTION

The antenna positioning unit (figure 1 and 2) allows the scanning of an area of 2 meters by 4 meters with 0.75 mm precision in both directions. The minimum step size is 0.5 mm and continuos antenna sweeps may be realised with a maximum displacement speed of about 130 mm/s in x-direction and 170 mm/s in the y-direction respectively. The gantry is mounted at the ceiling of the laboratory room to be able to place heavy test objects also. In order to simulate line arrays, the antenna dislocation system dispose of two separately moveable y-carriages on a common x-carriage. The network analyser has its own platform fixed on the x-axis to minimise RF-cable length and cable deflection. RF-, control-, and main-cables are put into flexible guidance chain channels. Telescopic plastic pipes allow manual antenna height adjustment with respect to the test objects. The maximum antenna weight shouldn't exceed 15 kg per carriage.

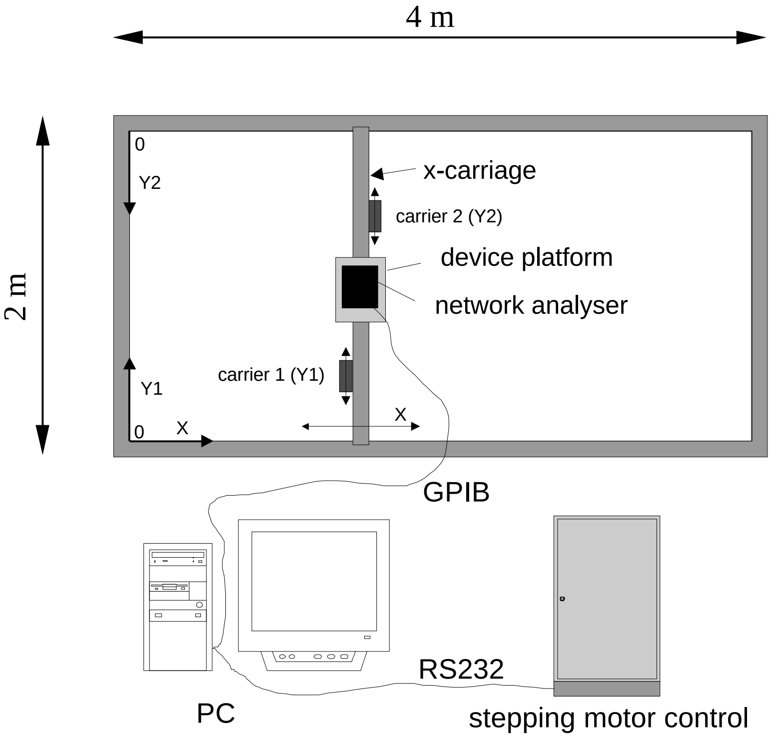


**Figure 1** Schematic top view of the positioning system

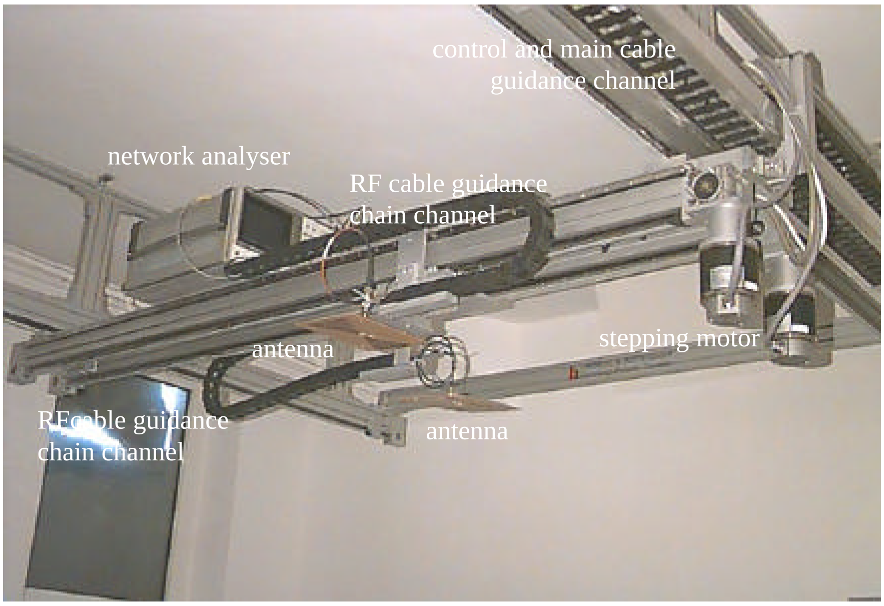


**Figure 2** Detail view

The precision of the antenna positioning permits the usage of wavelength up to 7.5 mm approximately. This corresponds to a maximum operation frequency of 40 GHz for propagation in air and of 10 GHz for propagation in a medium like concrete with $\varepsilon \approx 15$.

## III. MEASUREMENT SCHEME AND SYSTEM CONTROL

We mostly used a network analyser with time domain option as radar device in order to get a high flexibility in the measurement procedures and parameters. Such a device has the advantage of a high dynamic range, a selectable bandwidth, and gives the alternative of either frequency or time domain output data. The acquisition time of the network analyser is comparatively high and not acceptable for real time measurements. One scan demands several seconds depending on IF-bandwidth and number of samples. But in our automated laboratory environment the measurement speed is not a critical task.

There are a variety of scanning procedures. Most of them can be implemented with the help of the electrical scheme shown in figure 3. Since both antennas are mounted at different carriages, this allows both monostatic and bistatic measurements just as a multistatic acquisition by changing the antenna distance. With that, it is possible to simulate linear arrays by successive occupation of all antenna positions in the virtual array. On the condition of a high precision of the antenna positioning, measurements with different polarisation can be made by repeating the complete scanning process after turning the axis of one or both antennas by 90 degree.

The quotient A/R (monostatic mode) gives a measure of antenna mismatch and ground return. The transmission behaviour between both antennas (breakthrough, ground propagation) is characterised by the relation B/R (bistatic mode). Because of the different delay times in the diverse signal components, the time domain representation is the simplest way to separate undesired signals like mismatch return or breakthrough from the ground going signals to be examined.

The interconnection between the network analyser and the antennas is made by flexible coax-lines (WHU 18-1818-036). Due to the movement of the antenna carriage this cables will bend, which results in a phase error of max. 2 degree at 6 GHz or an additionally delay of about 1 ps respectively over the whole dislocation distance. This value is negligible with respect to the time ranges, which are ordinarily used (> 10 ns).

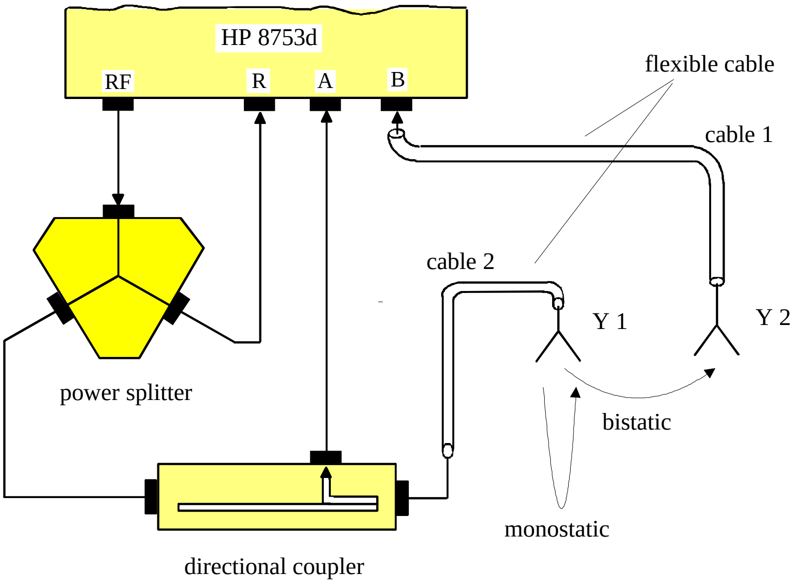
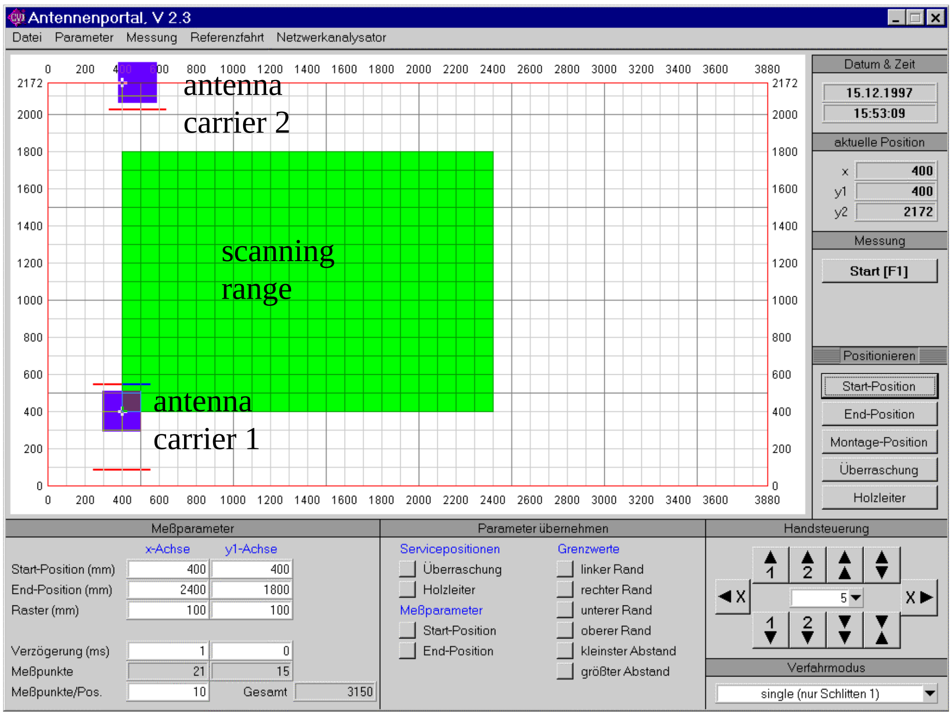


**Figure 3** Electrical scheme of the radar arrangement

The network analyser is controlled via GPIB and the portal via RS232 by a PC. A comprehensive currently upgraded control program with a dedicated graphical user interface (figure 4) allows automatic measurements with optimal operator support. Different scan opportunities are possible. The display of the remaining measurement time and the actual antenna positions give a permanent overview of the measurement status.



Datum & Zeit
15.12.1997
15:53:09

aktuelle Position
x 400
y1 400
y2 2172

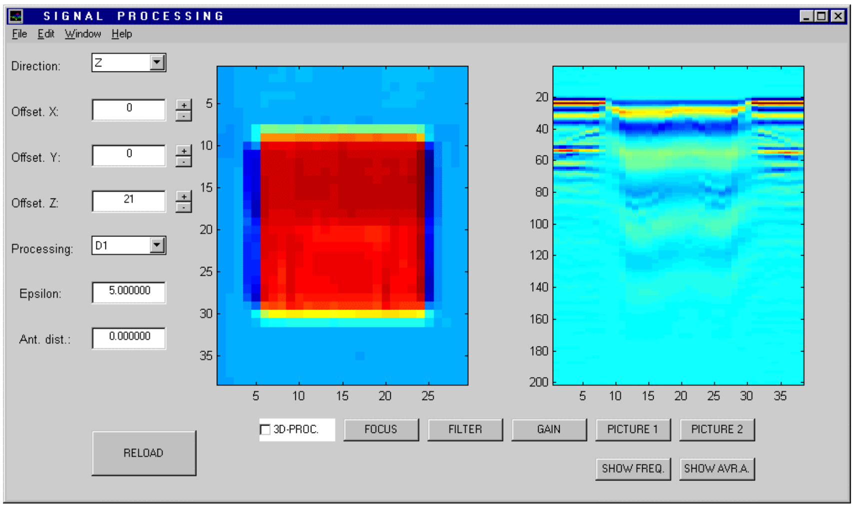
Meßparameter

| | x-Achse | y1-Achse |
|---|---|---|
| Start-Position (mm) | 400 | 400 |
| End-Position (mm) | 2400 | 1800 |
| Raster (mm) | 100 | 100 |
| Verzögerung (ms) | 1 | 0 |
| Meßpunkte | 21 | 15 |
| Meßpunkte/Pos. | 10 | Gesamt 3150 |

Handsteuerung: 5

Verfahrmodus: single (nur Schlitten 1)

**Figure 4** User interface to control the data acquisition of the imaging radar



Direction: Z
Offset. X: 0
Offset. Y: 0
Offset. Z: 21
Processing: D1
Epsilon: 5.000000
Ant. dist.: 0.000000

**Figure 5** User interface of 2D- and 3D-radar signal processing

## IV. SIGNAL STORING AND PROCESSING

The measurements with the network analyser are very time consuming. To preserve the data reliability and security, every scan is stored in a MATLAB-file immediately after the measurement was done. To process the data, at first a two- or three-dimensional MATLAB-matrix has to be build from these files. After that, the signal processing can start by using own algorithms or supported by a graphical interface with predefined one-, two- and three-dimensional operations (figure 5) [2]. Some examples are as follows:

- show slice images (profiles) in all directions,
- create movies of a radar volume data,
- subtract radar volumes,
- apply background removal, diverse filters, automatic gains,
- migrate profiles or volumes according Kirchhoff or Stolt algorithm.

## V. EXAMPLES AND PROBLEMS

*Antenna pattern measurement*:

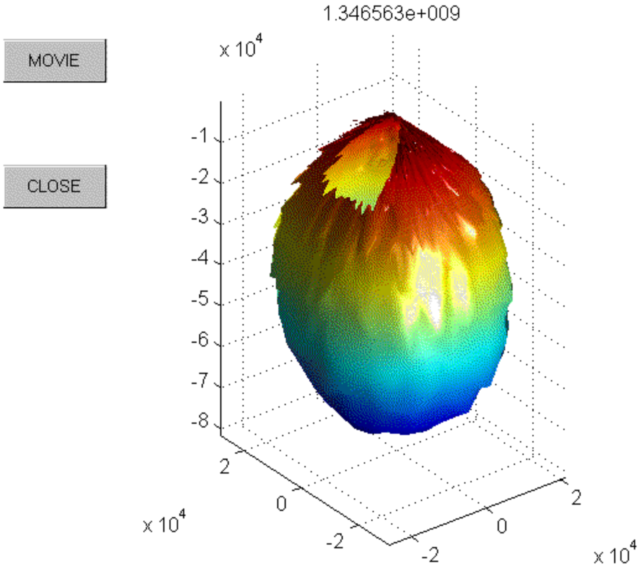


**Figure 6** 3D-directivity pattern

By moving a monostatic or bistatic antenna arrangement above an isotropic scatterer (sphere) it is possible to calculate the pattern of the dislocated antennas from the scattered field, even if the radar cross section of the scatterer is unknown [1]. This method may be used to determine the antenna pattern for propagation in both air and solids. The only need is a sphere within the propagation medium. Figure 6 shows an example of a three-dimensional directivity pattern of a test antenna for propagation in air at 1.34 GHz.

*Limited test objects*: As explained above, the aim of the experiments was antenna measurements and material investigations using a metallic sphere in the centre of a cube formed from four stones under test. Figure 7 gives an expression of the disassembled arrangement. But now, the limited volume of the test object causes some border effects in the scattered field which cover the reflection of the sphere (figure 8a). By repeating the same measurement without sphere and retaining the original positions of the stones, one gets a data set which contains only the border effect. The subtraction of both produces the wanted image (figure 8b) showing the typical hyperbola of a point scatterer. This is a critical procedure since any changes in the arrangement has to prevent except the replacement of the sphere. Secondary reflections may be cancelled by gating out those parts of the radar image that are caused only by first order reflections at the sphere. For it, the dimensions of the test volume should not be fixed too small. Regarding this, it will be possible to create real radar data of objects buried in unbounded media even though the measurements were done under restricted laboratory conditions.

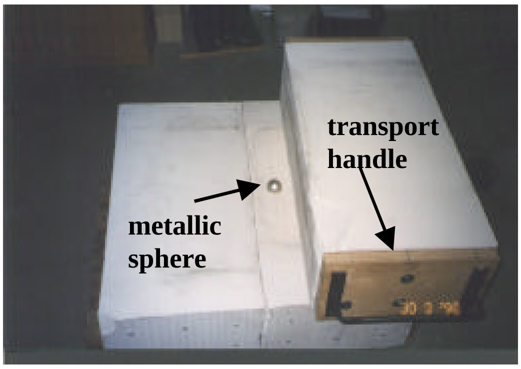
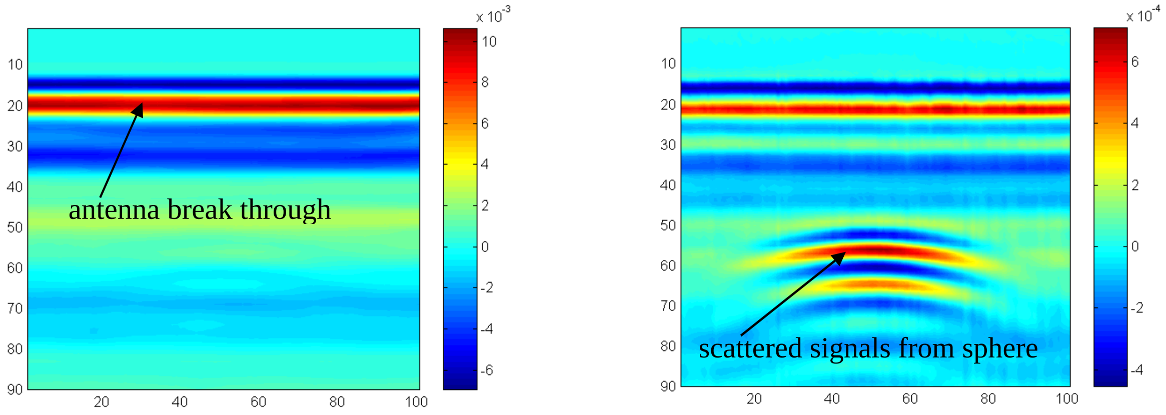


**Figure 7** AAC stones with buried spherical scatterer

*Handling of test objects*: The handling of solid test objects in a laboratory without lifting tools is not as simple as thought. For first experiments, we confined ourselves to relative light-weight materials like AAC stones[1]. The weight was about 80 kg of a 300 x 500 x 1000 mm$^3$ stone (figure 7). Since we need a high reproducibility in the positioning of the stones, this is the maximum which can be handled by two persons. Adequate problems arise if sandy materials will be used as embedding materials even if they have to be replaced in order to examine different soils.



a) original data

b) difference data

**Figure 8** Radar images of a metallic sphere buried in a cube of AAC stones.

## VI. CONCLUSION

A flexible programmable radar imaging equipment was presented which allows a lot of studies in imaging radar development and applications among other in non destructive testing in civil engineering. The problems of handling the test materials will solved in the future with help of adequate handling tools.

## VII. ACKNOWLEDGEMENTS

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## References

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[2] Practice report on Radar Signal Processing, MEODAT GmbH, R. Zetik

**Authors:**
Dipl.-Ing. R. Zetik, Technical University of Košice, Department of Electronics and multimedial communications, Park Komenského 13, 04001 Košice, Slovakia, e-mail: zetik@tuke.sk

Dr.-Ing. J. Sachs, Technical University of Ilmenau, Department of Electronic Measurement, P.O.B. 100565,
98684 Ilmenau, Tel.: 03677-69-2623, Fax:.03677-69-1113, e-mail: sac@e-technik.tu-ilmenau.de

Dr.-Ing. B. Schneegast, MEODAT GmbH, Ehrenbergstr. 11, 98693 Ilmenau
Tel.: 03677-668-651, Fax: 03677-668-655, e-mail: sne@meodat.de

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[1] Autoclaved Aerated Concrete (AAC) Hebel stones