# Through-Wall Imaging using Real-Aperture Radar

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## ABSTRACT

There are numerous occasions when it is desirable to inspect the interior of a room or building when physically entering the room may be either impossible or hazardous. These situations include civil engineering, search and rescue and law-enforcement scenarios. This contribution investigates the use of a relatively low-frequency, synthetically-focussed radar for through-wall imaging, it describes a number of experiments carried out using this radar and presents results from these experiments.

## INTRODUCTION

Radio waves can penetrate walls and it is therefore possible to use radar to image the interior of a room. Applications for this type of imaging are numerous and include urban search-and-rescue scenarios. While high frequency radio waves give excellent resolution and the possibility of detecting signs of human respiration [1], penetration depth through masonry walls is an obvious concern.

This contribution therefore investigates the use of a relatively low-frequency (1GHz) radar for through-wall imaging. Being low-frequency means that through-wall penetration is much improved and imaging process is less affected by the construction of the wall.

The radar system described herein makes use of a technique implemented by the authors, originally with application to detecting buried landmines. This technique - Real Aperture, Synthetically Organised Radar (RASOR) - employs a real 2D antenna aperture populated by $N$ antennas and transmits a pulse from each antenna element in turn. The echoes from each of the $N$ transmitting antennas are received by the other $N$-1 antennas. The combination of these $N(N-1)$ bistatic signal paths, described by this contribution, yields a significant processing gain, against clutter, compared to that achievable by conventional SAR.

## THEORY

The focussing concept that forms the basis of the work described herein was patented by Professor Ralph Benjamin and the University of Bristol [2]. For completeness, in this section the basic principle of operation is explained - further detail being available in the literature [2, 3].

In the RASOR scheme, all elements of a 2D antenna array transmit a broadband pulse in turn; all elements sharing any operationally relevant 3D field of view with the current transmit element then record the received signal $y$. By predicting the path delay from the transmit antenna $A$ via any desired resolution cell $C$ to any receiving antenna $B$, it is then possible to retrospectively extract *and time-align* all the signals from this - or any other - selected resolution cell.

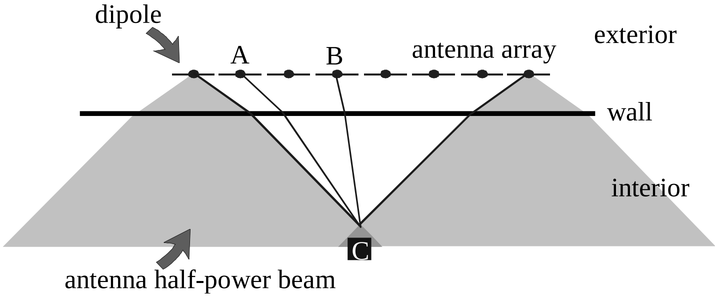

Fig. 1: Transmit antenna *A*, receive antenna *B*, resolution cell *C*.

Fig. 1 shows (in one dimension) the set of antenna elements that can observe a given resolution cell in the ground (including the effect of refraction). With $N$ elements, there are $N^2$ such paths. Duplexing problems make it unattractive to receive on the transmitting element. Since the total path would be the same if the transmit and receive function were interchanged, there are therefore $N(N-1)/2$ distinct paths per resolution cell.

The return from the resolution cell of interest is then computed by integrating the data over a window corresponding to the transmit pulse width $\tau$:

$$V = \int_0^{\tau} \left( \sum_{i=1}^{N(N-1)/2} w_i y_i (t - T_i) \right)^2 dt \qquad (1)$$

- where $w_i$ are weighting factors that may be applied to compensate for differences in the predicted attenuation between the paths and/or for the distinct clutter susceptibilities of these paths, $T_i$ is the predicted time-delay associated with the particular path.

An operational radar based on this principle has been constructed by the authors, employing an array of 7 x 8 printed bowtie dipole antennas and operating with a 70% bandwidth around a central frequency of 1.2GHz. It switches a single transmitter consecutively to all antennas, and at each antenna operates it repeatedly, so that a single receiver and digitiser (an 8 GSample/s digitising oscilloscope) can be switched to all relevant receiving antennas in turn. The bistatic use of all antennas within view of a target ensures that all potentially relevant signals are collected. The recorded data from the separate bistatic paths may then be coherently focused onto all potentially relevant resolution points in space by means of (1).

This radar was designed for the detection of buried anti-personnel landmines [3], however, with the array turned on its side, facing a wall, it becomes possible to use it to image into the room behind the wall. The next section describes a number of experiments carried out using the radar in this fashion.

## EXPERIMENTAL RESULTS

Initially the system was used to image a single human subject standing behind a single-skinned plasterboard wall, supported by timber uprights, and built within the relatively cluttered environment of a RF laboratory. Fig. 2 shows a plan view of the focussed signal, with the subject shown at precisely the correct location. As in all the data presented here, the presence of the wall and the mutual coupling between the elements are callibrated- or averaged-out.

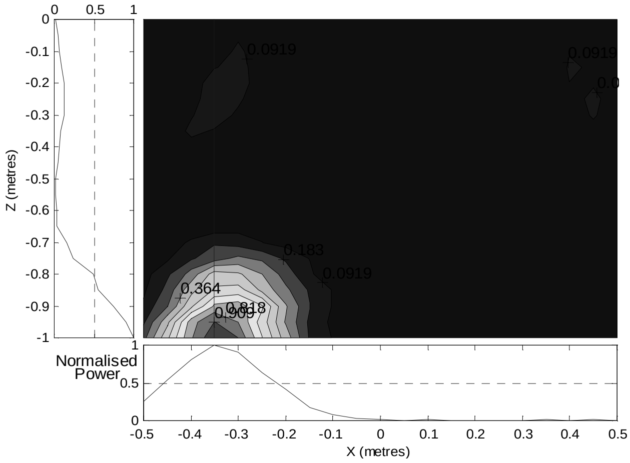

Fig. 2: Plan view (Human subject at x=-0.3m, z (distance from wall)=1m)

Subsequent experiments employed double-skinned plasterboard walls, typical of non-load-bearing domestic walls (Fig 3) and a solid breezeblock wall (as used for most load-bearing interior walls) (Fig. 4).

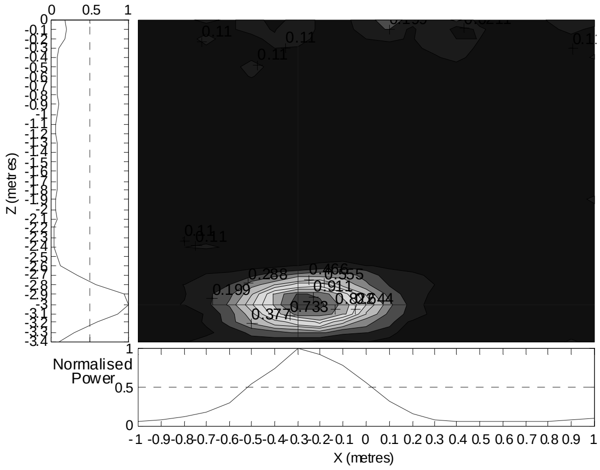

Fig. 3: Plan view with subject 3m from a double-skinned plasterboard wall (the greatest range that could be accomodated in the laboratory).

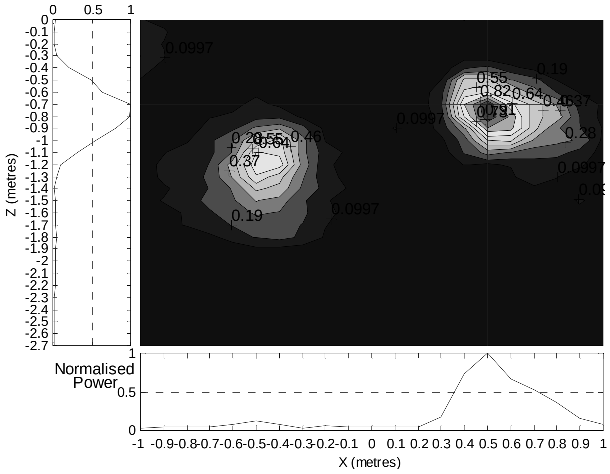

Fig. 4: Two subjects. One at x=0.4, z=0.7m from wall, the other at x=-0.4, z=1.2m from wall

Despite the relatively primitive nature of the experimental equipment (which was, in any case, designed for landmine detection), in all the above cases the detection was accomplished successfully.

## CONCLUSIONS

This contribution has described a set of preliminary experiments that demonstrate the use of a low-frequency real-aperture, synthetically-focussed radar for imaging the interior of a room. The experimental system has been shown to be able to detect human subjects at various distances from walls of varying construction. Considerable further work is required, and this will include imaging rooms containing a mixture of furniture and human subjects and the practical issue of deploying an antenna array (quite probably of an irregular shape) along an available wall surface.

## REFERENCES

[1] E. F. Greneker, "Radar Sensing of Heartbeat and Respiration at a Distance with Security Applications," *Proceedings of SPIE, Radar Sensor Technology II*, Vol. 3066, Orlando, Florida, pp. 22-27, April, 1997.

[2] R. Benjamin, 'Post-Reception Focusing In Remote Detection Systems', US patent 5,920,285, 6/7/99.

[3] R. Benjamin, I. J. Craddock, G. S. Hilton, E. McCutcheon, S. Litobarski, and R. Nilavalan, "Microwave Detection of Buried Mines using Non-Contact, Synthetic Near-Field Focusing", IEE Proceedings - Radar, Sonar and Navigation, Vol 148, pp 233-240, August 2001.