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A novel close-range imaging system

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Abstract

A coherent system with two FMCW or stepped frequency radar sensors separated by 1 - 2 m is presented for close range imaging. Resolution is achieved via range resolution from the two different sensor positions, exploiting both mono- and bistatic responses, thus give good facilities for multi-target scenarios. First test have been made using a vector measurement equipment for an antenna measurement range as radar simulator.

Introduction

Imaging of different scenes, even under adverse environmental conditions, is playing an important role for a number of applications like autonomous vehicles (robots) or as a collision warning for cars driving forwards or backwards or changing the lane /1/-/3/. In a number of these scenarios, an imaging of the relevant area around the vehicle has to be performed. In most cases, this is done by a scanning antenna with a narrow beamwidth in azimuth /3/, /4/.

This requires, however, antennas with relatively large lateral dimensions combined with mechanical /3/ or electronic scanning, e. g. frequency scanning /4/, resulting in large and expensive antenna arrangements. For close-range imaging, on the other hand, an imaging is possible, too, by doing separate measurement from at least two different positions via range, using wide beamwidth antennas. Therefore, a novel system for close-range imaging is proposed using two antennas separated by 1 to 2 m.

Description of the Arrangement

The proposed arrangement consists of two radar sensors separated by approximately the width of the respective vehicle. The antennas have a wide beam in azimuth whereas, typically, a narrower beamwidth is desirable in elevation. In the first test conducted in our laboratory, H-plane waveguide horns with horizontal polarization and beam widths of 77° in azimuth and 12° in elevation and a gain of about 15 dBi were employed (Fig. 1). For a single target, each sensor gives a monostatic as well as a bistatic response according to the distance; taking into account reciprocity, three independent sets of data are available for each target described by two circles around each antenna and an ellipse with the antennas as focal points (Fig. 2). This already gives some means to separate multi-target scenarios; this can be improved considerably by employing a coherent sensor system. For system simplicity and for minimal EIRP, FMCW- or stepped frequency sensors are advantageous. For a stepped frequency system, a coherent evaluation of the measured data can be done by

$$A(P)=\frac{1}{r_{1P}}\sum_{i=1}^{N}E_{i1}\cdot e^{j2k_i r_{1P}}+\frac{1}{r_{2P}}\sum_{i=1}^{N}E_{i2}\cdot e^{j2k_i r_{2P}}$$
$$+\sum_{i=1}^{N}\frac{1}{\sqrt{r_{1P}\cdot r_{2P}}}E_{i2}\cdot e^{jk_i(r_{1P}+r_{2P})}$$

where A(P) is the amplitude at some target in point P, E_{i1} and E_{i2} are the measured electric fields at frequency point i at antenna 1 and 2, respectively. In the third term of this equation, E_{i2} could equally be replaced by E_{i1} due to reciprocity. r_{1P} and r_{2P} are the distances between antenna 1 or antenna 2 and the target. For the amplitude dependence, the far field approximation of the Hankel function for cylindrical problems is assumed. The summation is done over the number N of measured frequency points. The overall measurement bandwidth determines the sensor resolution $\Delta R = c_0 / (2\Delta f)$, while N determines the unambiguous range of the sensor system $R_{unamb} = N \cdot \Delta R$. Possible frequencies of operation may be around 24, 61, or 77 GHz; The maximum range of interest as well as the required bandwidth, and therefore the required transmitter power are very small, therefore, a bandwidth in the range of 1 GHz (or even higher) may be reasonable, resulting in a resolution of 15 cm (or better).

First Experimental Simulations

Using an antenna range with a vector network analyser as measurement system and an offline data processing, preliminary tests around 24 GHz with varying bandwidths have been made. As a first test scenario, two metal plates of 0.5 and 0.3 m width, separated by 0.7 m and placed at a distance of 5.6 m from the antenna basis, have been chosen. The results for a 1 GHz bandwidth are displayed in Fig. 3. A more complex arrangement consisting of four metal cylinders as shown in Fig. 4 was chosen for the second test. The results are given in Fig. 5 for a 11 GHz as well as a 1 GHz bandwidths. The setup of the targets can be clearly recognized. For increasing distance, the system response is widened which can easily be explained by the geometrical presentation in Fig. 2; the angles between the two circles and the ellipse become more and more smaller. All these results were evaluated without special windowing.

In a next step, tests were performed in the more complex environment of a laboratory and workshop hall. Two cylinders were placed in front of a scenario of a pile for power supply, tables, and lockers (Fig. 6, top), with some power supply troughings buried in the floor. Due to the required cable lengths from the measurement system to the antennas, the transmitter power amounted to -20 dBm, the receiver noise figure was in the range of 40 dB. For this scenario, different windowing methods were investigated to improve the contrast of the measurements /5/, /6/; as the best solution, a Tukey window (tapered cosine) was found, giving the best compromise between side lobe suppression and degradation of resolution. In Fig. 6 (bottom), measurements of this arrangement are plotted with Tukey windowing (f=25GHz, bandwidth 1 GHz). The cylinders can be seen in front of the other strong reflections; and the range without obstacles can clearly be detected.

Conclusion

The principle of a novel close range radar sensor for possible applications with small autonomous vehicles or as a automotive sensor for driving backwards has been demonstrated. Further work will be done to build up a mobile test system, to conduct more realistic experiments, and to improve the signal processing of this system.

References

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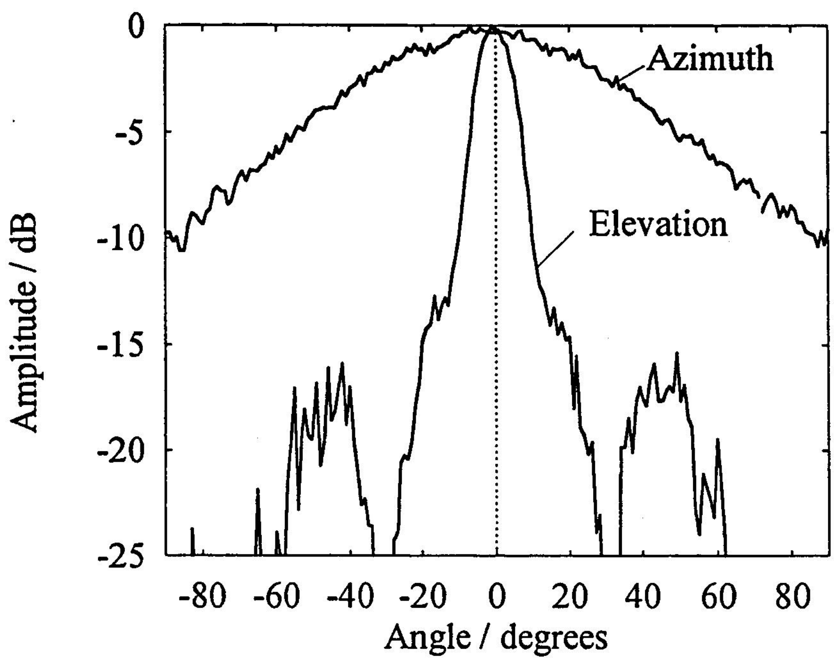

Fig. 1: Azimuth and elevation radiation diagram of test antennas.

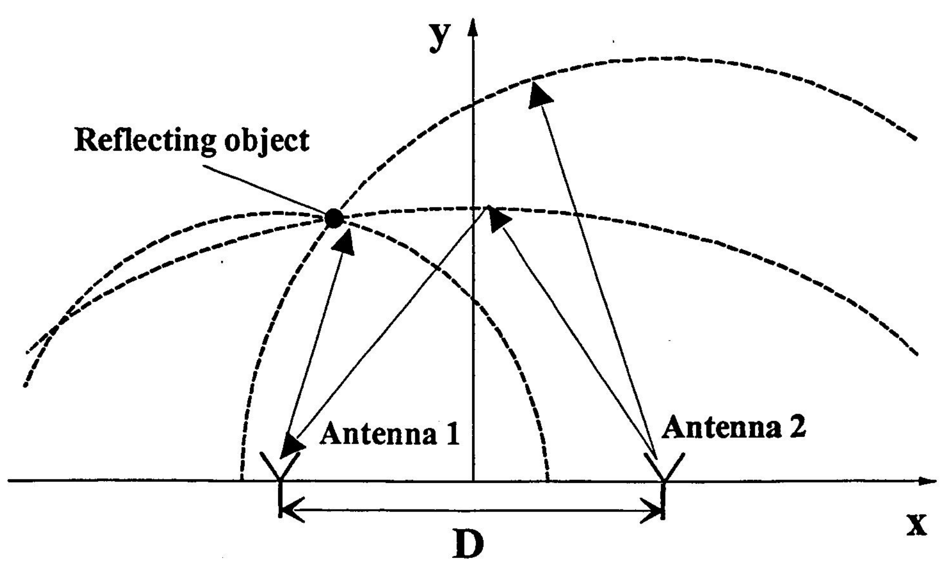

Fig. 2: Geometrical arrangement of imaging system

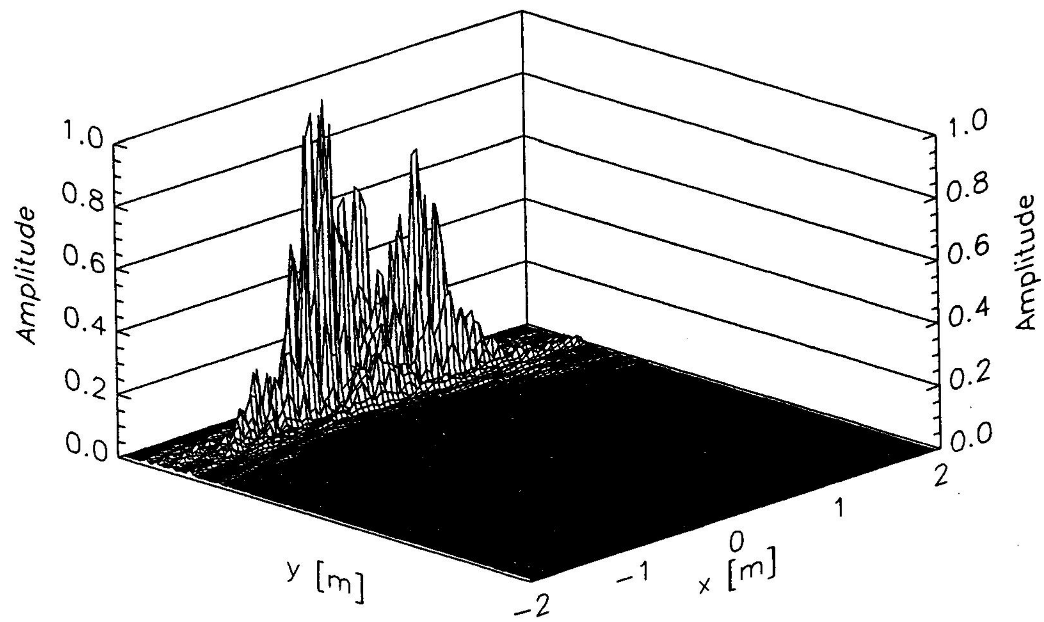

Fig. 3: Image of 2 metal plates of width 0.5 and 0.3 m separated by 0.7 m at a distance of 5.6 m from the antennas (bandwidth 1 GHz).

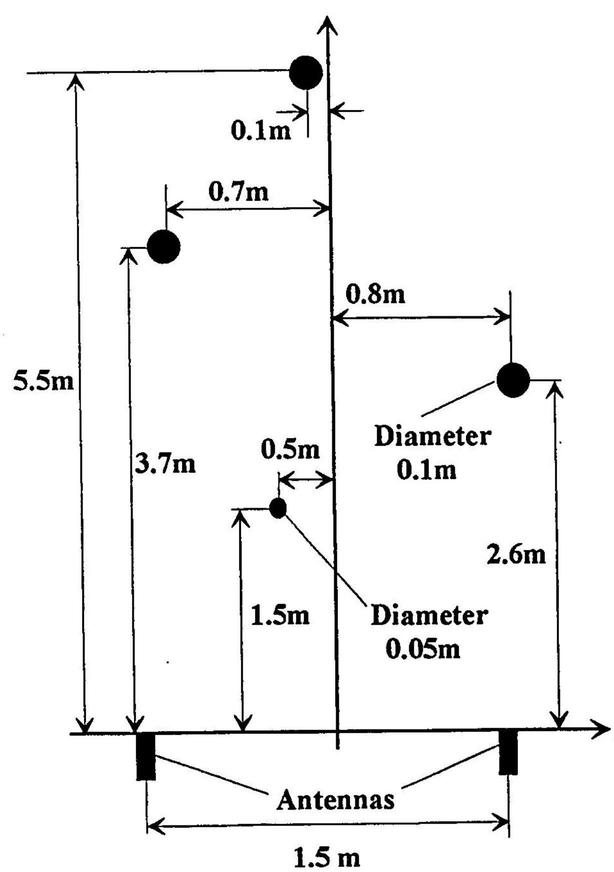

Fig. 4: Geometrical arrangement of 4 metal cylinders and resulting image

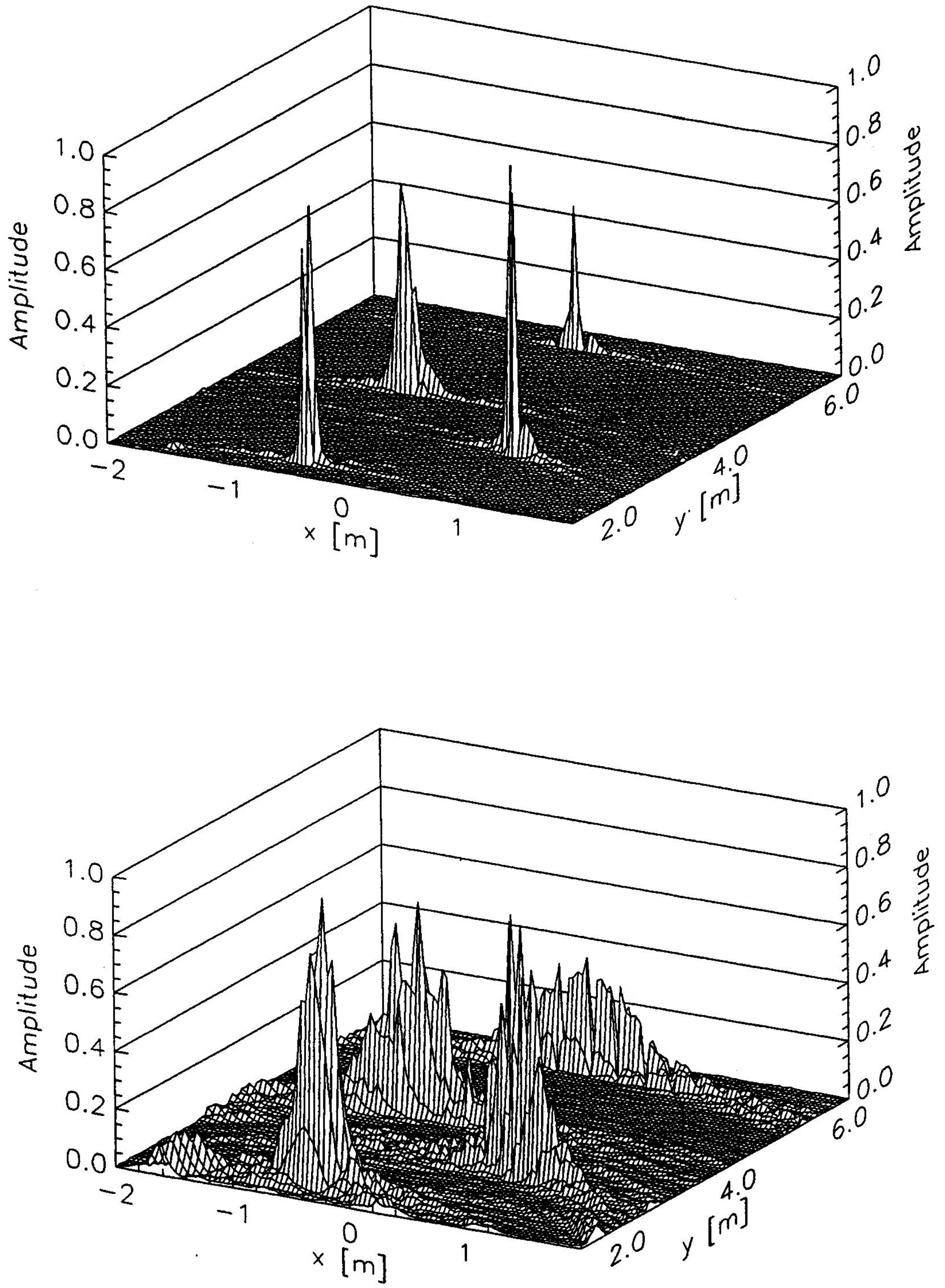

Fig. 5: Images of 4 cylinder arrangement according to Fig. 4 with 11 (top) and 1 GHz (bottom) bandwidths.

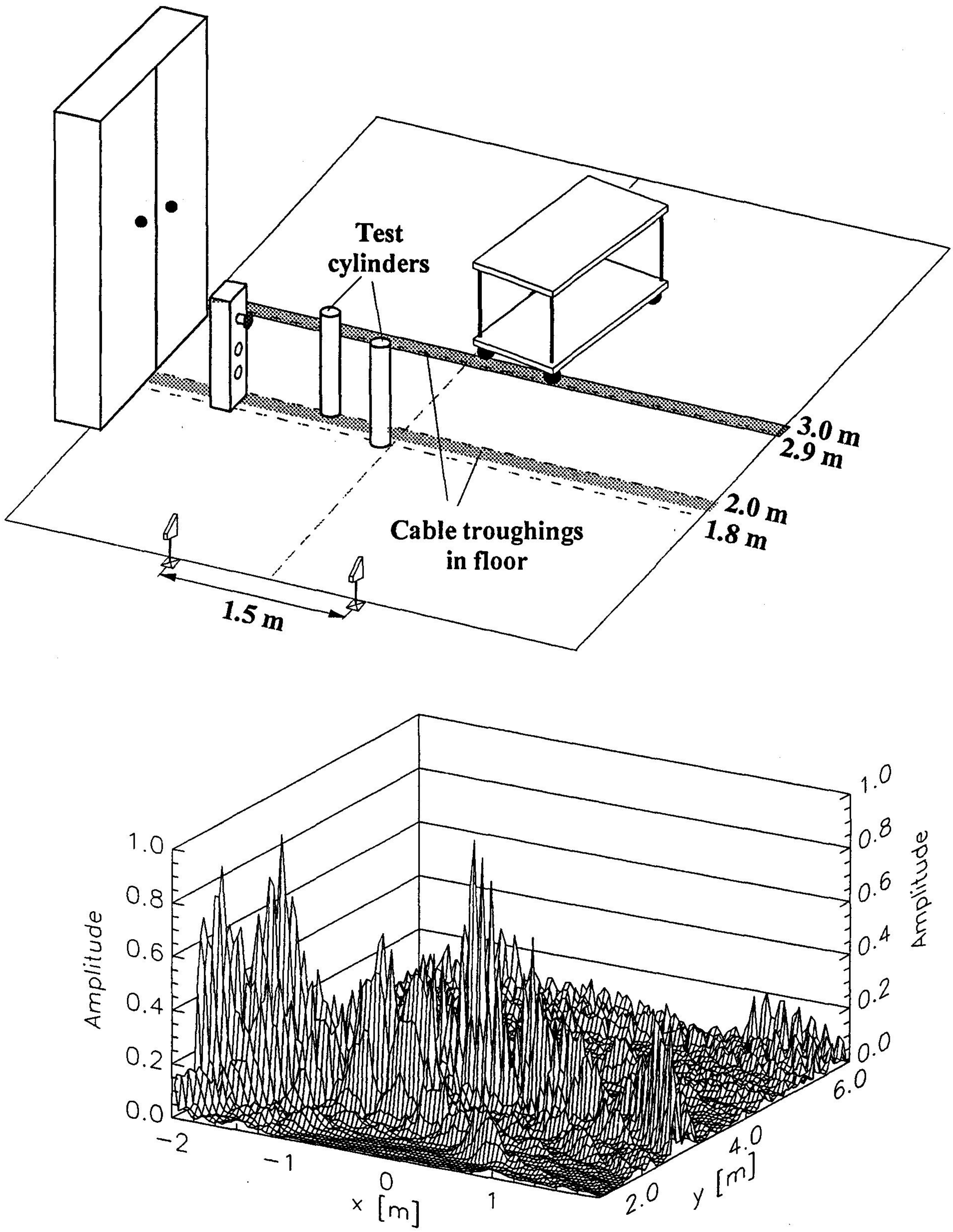

Fig. 6: Basic arrangement of 2 cylinders in a laboratory/workshop environment and resulting image with 1 GHz bandwidth and Tukey windowing.