A 3-D Millimeterwave Luggage Scanner

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***Abstract*— A light weight, transportable measurement system for the inspection of suspicious luggage in a threat situation has been developed, based upon miniaturized millimetre wave radar modules operating at W-band. To allow for a sufficient detection capability of objects hidden within a piece of ownerless luggage within a passenger terminal at a sufficiently short scanning time, a radar approach rather than a passive radiometer technique was chosen.. It is generally recognized, that only synthetic aperture is able to supply a sufficient geometrical resolution at high imaging speed. Moreover a radar can also deliver a three dimensional description for the position and the shape of a concealed object using high range resolution techniques.**

The paper describes the measurement set-up and the evaluation algorithm. Typical examples for different set-ups are presented.

I. INTRODUCTION AND BACKGROUND

NEW sensors used for security purposes have to cover the non invasive control of men and baggage with the aim to detect weapons, explosives and chemical or biological threat material. While X-ray systems would give the best performance for such applications, they are critical in use against people and mostly too bulky as to allow a rapid operation at any place within a passenger terminal. The capability of millimeterwave and terahertz wavelengths to look through textile material and the possibility to achieve a geometric resolution, which is sufficient to resolve critical items within the necessary range, make them attractive for mobile luggage inspection systems based upon the radar principle. Synthetic aperture processing offers the advantage to achieve high lateral resolution using antennas with small aperture.

Due to other applications, civilian and military, the frequency region around 94 GHz is technologically best developed. As well devices and components have been designed and built and exhibit a high degree of maturity. Key components are low noise and medium power HEMT amplifiers and miniaturized single chip FM-CW radars at 94 GHz as developed by Fraunhofer-IAF [1]. For the application discussed here, not only the front-end hardware is a challenge, but also the adaption of SAR processing to the close range geometry. In contrary to radiometric approaches for security scanners [2], radar offers the capability to assess the third dimension using the inherent ability to determine range.

II. RESULTS

The radar modules used for the demonstrator described here were operated in a FM-CW mode, thus guaranteeing the highest possible average power. The modules used for the demonstrator offer an output power of 2 mW at 94 GHz and a bandwidth of 8 GHz, resulting in a theoretical range resolution of about 2 cm. The noise figure of the receiver LNA is below 3 dB. Figure 1 shows the 94-GHz radar module [1], while figure 2 demonstrates typical performance data.

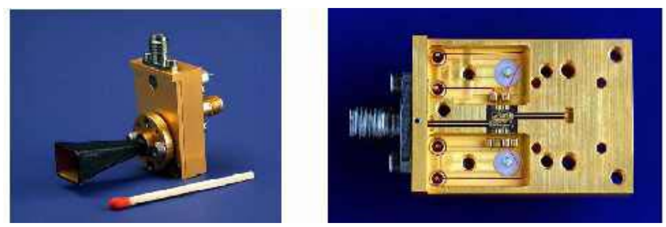

Figure 1: 94-GHz-Radar-Module used for the Scanner

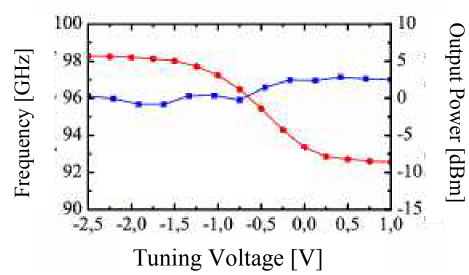

Figure 2: Performance Data of Radar Module

The radar module was mounted on a construction of two linear drives one put upon the other allowing for a movement in orthogonal directions. The length of each linear drive defines the synthetic aperture in that direction. Figure 3 demonstrates the geometry and shows a photo of the luggage scanner.

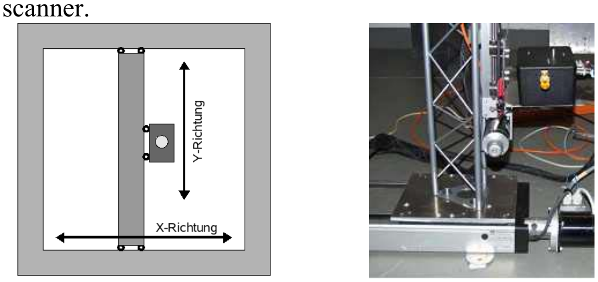

Figure 3: Geometry and Experimental Set-Up of Luggage Scanner

To achieve a sufficient image quality appropriate correction algorithms have to consider as well the nonlinearity of the chirp modulation as the near field effects. Preconditions for the SAR approach are a sufficient radar bandwidth, and a sufficient spatial region has to be illuminated by the antenna

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aperture, and the sampled volume should be suited to cover the required unambiguous interval. For an arbitrary aperture only the exact backprojection algorithm delivers the correct solution for the reconstruction of the scattering centre distribution from the measured data. This solution is extremely difficult to achieve and requires a very high amount of calculation as for each image point a three dimensional integral has to be evaluated. The way how the problem is solved here and what is demonstrated in figure 4, is to focus upon an image point in the centre of the observed volume.

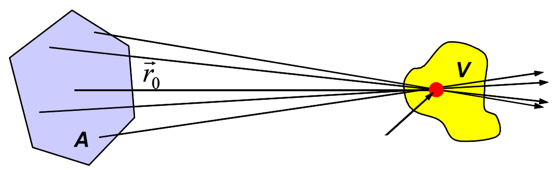

Figure 4: Geometrical Model of Focussing Approach

The first step derives a phase compensation with the factor C.

$$S^*(f,\vec{r}_a)=S(f,\vec{r}_a)\cdot C(\vec{r}_a)=S(f,\vec{r}_a)\cdot \exp\left(-j\cdot 4\pi\cdot f\cdot \frac{R(\vec{r}_a,\vec{0})}{c_0}\right)$$

The second requires a polar reformatting of the data.
This is done under three assumptions:

- The curvature of the EM waves in the vicinity of the scatterer is negligible (plane waves)
- During the reformatting the data are transformed from circular coordinates to a carthesian system
- As fastes method the nearest neighbour approach is taken

A more advanced resampling method could lead to an improved result. As a third step a transformation into the frequency domain is performed as sketched in Figure 5..

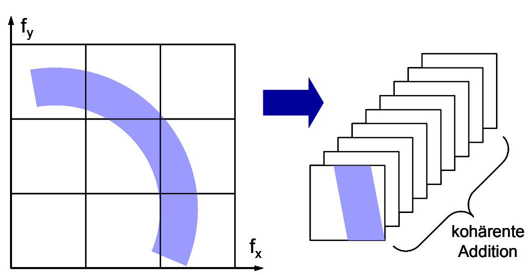

Figure 5: Convolution into Frequency Domain

The final step is the image reconstruction using a FFT. The resulting image is well focussed in the vicinity of the reference point. The sharpness is decreasing with increasing distance from this point.

The algorithm developed for the demonstrator is capable to deliver a proper 3-dimensional image for the content of a suitcase at a measuring distance of about 1 m. Figure 6 shows a photo of a suitcase with hidden gun together with a two-dimensional representation of the scene deduced from data from a two dimensional scan with respective SAR processing and a three-dimensional representation of the hidden gun within the closed suitcase.

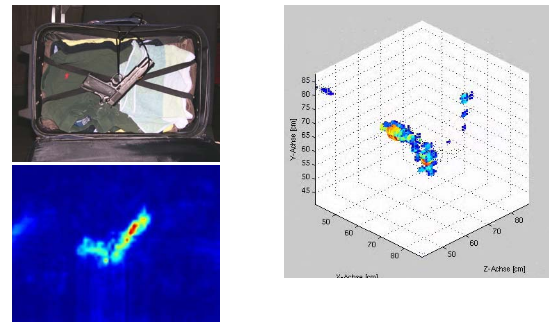

Figure 6: Photo of Suitcase with Gun, 2-D and 3-D SAR images

The tests described above were conducted with one single radar module mounted upon the scanner. An improvement could be implemented by using two receivers at orthogonal polarizations. The data would allow to discriminate between odd and even scatterers and such deliver valuable information for target classification. Respective work is currently underway.

REFERENCES

[1] A. Tessmann, S. Kudszus, T. Feltgen, M. Riessle, C. Sklarczyk, W. Haydl, “Compact Single-Chip W-Band FMCW Radar Modules for Commercial High-Resolution Sensor Applications”, IEEE Transactions on Microwave Theory and Techniques 50 (2002), 2995.

[2] H. Essen, D. Nöthel, J. Huck, “Concealed Weapon Detection with a Passive Millimeterwave Scanning System”, Intl. Conf. on mm-Waves and Infrared, Boston 2005