Imaging of Concealed Weapons and Improvised Explosive Devices using Millimeterwave Technology

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ABSTRACT

Sensors used for security purposes have to cover the non invasive control of men as well as surroundings of buildings and camps. Military checkpoint protection against terrorists carrying weapons or bomb belts is one of the most important tasks to be taken in this domain. Special work has to be done to solve the disadvantages of commonly used systems like metal detectors. Another request is to develop systems, which are lighter, more modular and have a higher sensitivity. The work described in this paper concentrates mainly on sensors at 0.1 and 0.2 THz, which - in contrast to the above mentioned systems - are able to detect non metallic objects like ceramic knifes. In addition standoff surveillance is possible which is of high importance with regard to suicide bombers. To help operators of future sensor systems images with high resolution will be generated or even overlaid on optical images. The used systems - active as well as passive - are based on state-of-the-art solid-state components. Since the resulting detection probability depends not only on the sensor properties, but also on the signal processing, more and more effort is put into the enhancement of the data and its fusion with other sensor outputs.

1.0 INTRODUCTION

Security checks are getting more and more common in several areas of life. These can be a nuisance for passengers or visitors undergoing the security checks, as today's approaches tend to take more and more time compared to the flight or venue itself. On the other hand, the security personnel face increasing numbers of people to be screened. Taking into account that each technical aid, like metal detectors and X-ray machines, can only deliver a limited set of information, each new system can add an indication which may help to distinguish actual threat material from other items. This, in turn, can help to increase overall security while reducing the annoyance that a security check can be today. As in former times, when passengers at airports spent most of their time waiting for their luggage or mounting the airplane, now more and more time has to be spent on the security checks. Also, the threat has changed, because terrorists prepare to mislead classical metal detectors. This is why new systems are necessary, which are capable of detecting concealed weapons and explosives, even if they are not made of metal.

Furthermore, mm-wave imaging, as well as active radar techniques, can be used to operate in a standoff scenario. This means that persons can be screened at distances of up to 20 meters. This field of application will be very important in the future, to detect a potential danger already before the hazardous person can enter a sensitive area or building.

2.0 RADIOMETRIC IMAGING

2.1 Main principle

One possible approach to detect concealed weapons is by using radiometric systems. In principle, a scanner using this technique measures the thermal noise of the radiation reflected by the body. This is equivalent to the temperature on the surface of the body. The detection and imaging of objects concealed under the clothing is based on the fact, that different materials exhibit different radiation temperatures T_B depending on their own temperature and their physical properties. It is a linear combination of absorptive/emissive (ε), reflective (ρ) and transmittive (τ) characteristics: $T_B = \varepsilon T_O + \rho T_U + \tau T_E$. T_O is the physical temperature of the object, T_U the environmental temperature and T_E the background temperature. At mm-wave frequencies, the radiation is capable of penetrating clothes and other materials, with transmittivities of $\tau = 0.3\ldots0.8$. It is obvious that due to these different properties, objects differing from skin and fabric can be detected. This is possible over a wide range of frequencies, but a compromise has to be found between best contrast conditions at lower frequencies and better real beam imaging properties with a given antenna diameter at higher frequencies. In addition, some materials like explosives are transparent in lower frequencies, so to detect them as they reflect the surrounding radiation, higher frequencies should be used. In contrast, fabrics where these explosives may be hidden under are also more transparent at lower frequencies. Here, a good agreement between high- and low frequencies should be found as well.

2.2 Experimental setup

Up to now, most of our experimental setups were well suited for close distance scanning, with the advantage of givin very clear and detailed images of measured persons and concealed weapons. In this paper we concentrate mainly on standoff detection. The systems presented here work at 220 GHz, with some 94 GHz results being shown as well for comparison. Although the atmospheric attenuation is generally considered to increase with frequency in the mm-wave band, there are frequency ranges around 220 GHz, which lend themselves to imaging purposes. because they exhibit relative low attenuation. This makes it possible to look through clothes even under standoff conditions.

The radiometric system consists of a Cassegrain antenna mounted on top of a pedestal. The aperture has to be moved to point the single beam of the system to each measured spot on the target to be observed. Up to now, this movement gives the limitation in scanning time. Figure 1 shows the system setup.

The radiometric part consists of three LNA stages, as shown in Figure 2.

Figure 1: Radiometric System for standoff detection of concealed weapons working at 220 GHz.

The radiometer used here is a Dicke-type direct receiver using either a PIN-switch or – as shown in Figure 1 – a chopper wheel. So, for stability reasons, the received signal is compared to a fixed noise temperature, and drifts caused by the very sensitive amplifiers are cancelled. The 220 GHz LNAs were supplied by FhG-IAF and represent the most advanced MMIC LNA type available with respect to noise figure [1].

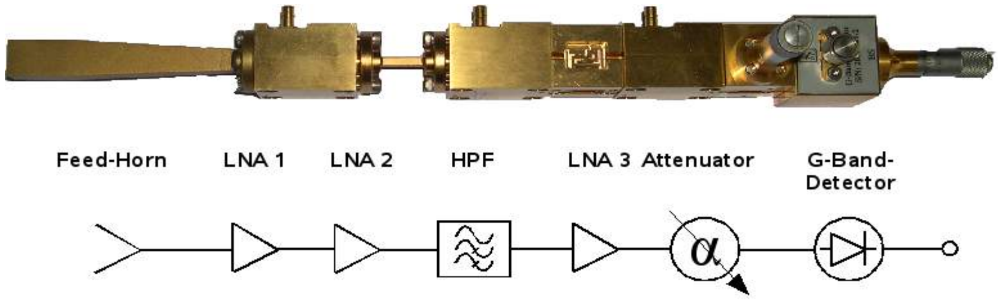

Figure 2: Photograph of the 220 GHz front-end. From left to right: Receiving horn, first LNA stage, second LNA stage, high-pass filter, third LNA stage, attenuator and detector.

Chopper Wheel	
Frequency	200 Hz
LNAs	
Bandwidth	>10 GHz
Noise Figure	10 dB
Radiometer	
Gain	>50 dB
System Noise Temperature	2000 K
Temperature Resolution	~0.12 K

Table 1: Performance of individual components and overall radiometer channel.

Figure 2 shows a photograph of the receiver, when using a chopper wheel for calibration. Alternatively, a PIN-switch is mounted between the horn and the first LNA stage. The total gain of the receiver is more than 50 dB, giving a noise temperature of about 2000 K. Figure 3 shows a photograph of a four-stage 220 GHz low-noise amplifier MMIC. The G-band LNA was designed by FhG-IAF to achieve high gain in combination with a low noise figure at 220 GHz, which is also shown in Figure 3.

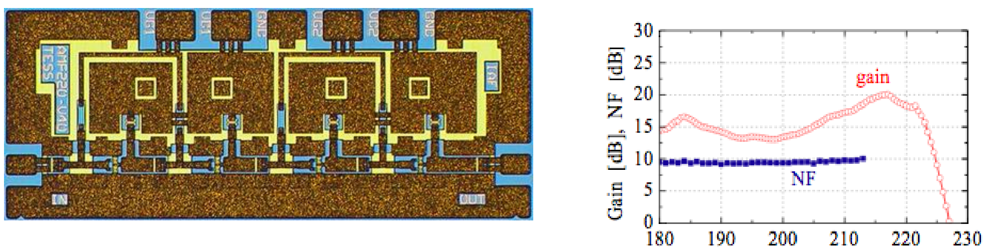

Figure 3: Left: Chip photograph of a four-stage 220 GHz cascode low-noise amplifier MMIC. The chip-size is 1x2.5mm². Right: Measured gain and noise figure (NF) of a 220 GHz low-noise amplifier module.

2.3 Typical measurement results

The shown standoff measurements were carried out outdoors. Because the system was equipped with a single receiver, the two feet dish had to be moved completely for real aperture scans. Therefore, a single measurement at 220 GHz took about 20 minutes to complete. The person was standing 10 m away from the measurement device.

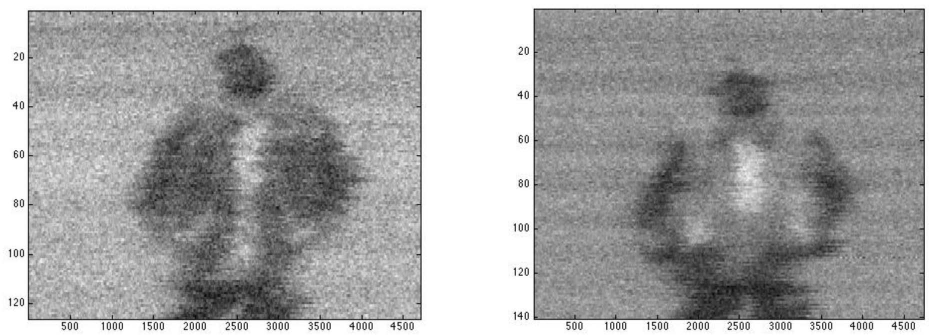

Figure 4: Scan of a person at 10 m distance. Left: Without bomb vest or weapon. Right: Person wearing a bomb vest under the coat.

The person measured in Figure 4 and Figure 5 was wearing different weapons or alternatively a bomb vest beneath the clothes. The bomb vest was fabricated by putting debris from metal together with screws into plastic cylinders. By filling up the cylinders with plastic glue, the signature of a real bomb vest could be simulated.

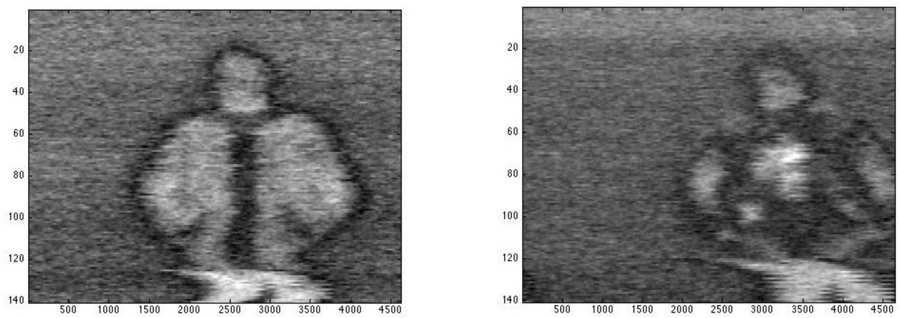

Figure 5: Scan of a person. Left: Without weapon. Right: With hidden weapon. The gun worn at the chest can be clearly identified.

In all shown radiometric images (Figure 4 and 5) you can see a bright band going from the throat down to the belly. This is the part of the jacket where the zipper was closed.

For additional tests, optical images and radiometric measurements were superimposed to get a better understanding of where hazardous objects have been worn. To implement this feature, a picture was taken from the exactly same direction as the mm-wave camera was looking. The radiometric images were then piped through a thresholding algorithm and then superimposed onto the black and white optical image. Figure 7 shows examples of these measurements. In the left picture the bomb vest can be seen clearly, together with the belt-buckle. The right picture shows a hidden gun worn in front of the chest, as well as some metallic object hidden in the right pocket.

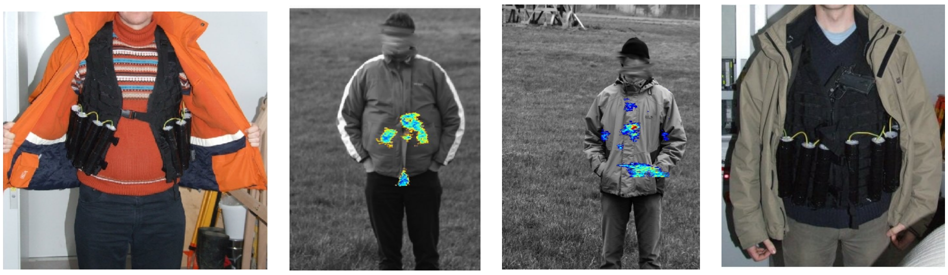

Figure 6: Optical image of scanned persons. The prominent parts of the radiometric images have been superimposed on the images. In the left picture the bomb vest worn beneath the jacket can clearly be seen. Additionally, you can see the belt-buckle. On the right image the hidden gun can be clearly identified together with some metallic object hidden in the right pocket.

Figure 7 shows a standoff scene which was scanned for test purposes. To increase the contrast in this measurement, the person and the bicycle were put in front of an absorber material, so the reflection of the diffuse illumination gives a very good image quality. By deconvolving the data with the measured beam, a better image quality can be achieved. The measured beam size is 0.23° FWHM, which is close to the theoretical value of 0.18° using the above configuration at 220 GHz.

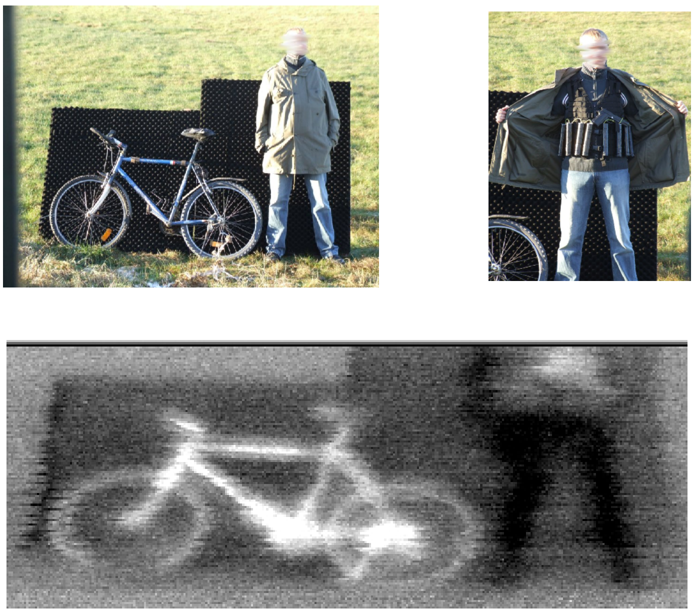

Figure 7: Radiometric image at 220 GHz showing a bicycle and a person wearing a bomb vest underneath the jacket. Person and bicycle were standing in front of absorber material to increase the contrast. The radiometric image on the left represents raw data, on the right side the image after post-processing is shown.

A comparison of the current 220 GHz sensor with the output from a current 94 GHz system (Figure 8) shows that significant progress has been made to exploit the potential benefits of the higher frequency range. On the system level, the main difference is at the moment that components in the W-band tend to be more mature and stable over time and temperature. In this band, channel stabilization methods, like the Dicke principle or noise injection, can in many cases be discarded in favour of total power receivers. This is highly desirable, since it makes the receiver channels simpler and increases the temperature sensitivity. With 220 GHz LNAs, the effort necessary to obtain a stabilized receiver is considerably higher. Currently, a voice-coil switch is integrated with the 220 GHz sensor, in order to replace the chopper wheel. Additional temperature stabilization is also under development.

Figure 8: Output from a current 94 GHz imaging radiometer at a scanning distance of 17 m. Left: Person unarmed. Right: Person equipped with bomb belt under the jacket.

3. ACTIVE APPROACH USING RADAR-ISAR TECHNIQUES

Another approach for standoff concealed weapon detection is the use of active radar sensors. We will describe two different systems here, the single chip FM-CW radar used at a security check door, and the experimental coherent broadband radar KOBRA, working at distances of 135 m.

3.1 Miniaturized 94-GHz Radar

This demonstrator consists of a single chip FM-CW radar [2] at 94 GHz. The radar module is mounted above the person to be screened. The module is then moved across the person, so using the synthetic aperture principle (SAR) a real image from the range-Doppler information can be created. The main advantage of this system compared to the passive radiometric systems is the very fast scanning speed. Unfortunately, in contrast to the passive approach, a monostatic or bistatic configuration is used, so illumination is not homogeneous. Thus hidden objects may be well located, but in most cases they cannot be identified. To help the operator, a video camera takes images from approximately the same angle as the radar to enable a correlation between optical features and radar targets. Both images are overlapped and shown on a PC in real-time. Because the radar is operating at a bandwidth of 8 GHz, a range resolution of about 2cm can be archived.

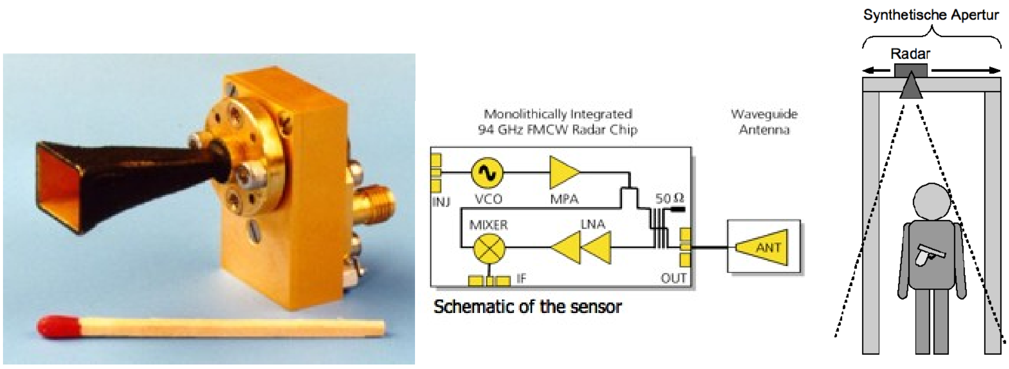

Figure 9: Miniturized 94 GHz FM-CW Radar module and block diagram of the sensor. The right picture shows the principle of the SAR-system.

3.2 Results with the 94-GHz SAR-Radar

Figure 10 shows measurements with the 94 GHz FM-CW Radar module. Color is given by the range-Doppler measurements combined with an appropriate thresholding algorithm. By combining this image with the simultaneously taken video image in black and white, suspicious objects can be detected easily. Tests with various metallic objects and the use of different adaptive thresholding schemes show a high reliability of this system for the detection of metallic objects. Because the scanning time of one second per person to be screened is very short, this kind of system can be used for security checks with a high throughput like at airports.

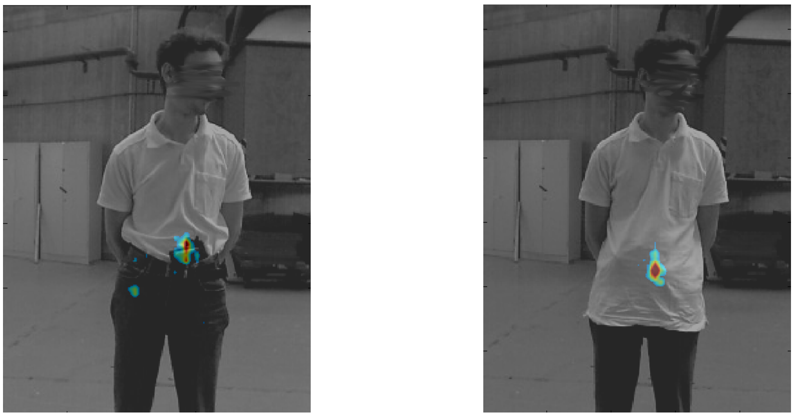

Figure 10: SAR measurement at 94GHz. The optical image is superposed by the radar image. This gives a good impression, where hidden objects can be found. Size and shape of the objects cannot be seen so easily.

3.3 Coherent Broadband Radar KOBRA

The Coherent Broadband Radar KOBRA is an experimental radar system working at 10 GHz, 35GHz, 94 GHz and 220 GHz. In all frequency-bands the bandwidth is 4 GHz, except for the 220 GHz band, where a bandwidth of 8 GHz and thus a range resolution of down to 1.7cm can be reached [3]. Usually the system is used for ISAR and RCS measurements of vehicles, but tests show, that also persons can be imaged at high distances of about 135 m. To take a full picture of the person, he has to lie down on a turntable and a full 360-degree scan has to be performed. This lasts approximately 2 minutes. Because the measurements were done for demonstration purpose only, this time period could be tolerated.

3.4 Typical ISAR-Radar measurements at 220 GHz

Figure 11 shows a typical measurement with the 220 GHz Broadband Radar. The person had to lie on the turntable and was wearing a gun beneath the shirt. This object together with the watch could be easily seen in the ISAR measurement.

Figure 11: Typical ISAR measurements of a person lying down on the turntable. The measurement distance was 135 m at a frequency of 220 GHz and 8GHz bandwidth. Measurement time was 2 minutes. In the left picture the person was wearing a bomb vest. The tubes filled with metal can easily be recognized.

4. CONCLUSION

Two approaches for concealed weapon detection were shown, one using a radiometer, the other employing FM-CW radar systems and SAR / ISAR techniques. The passive system delivers encouraging results with a good image quality and the possibility for standoff detection, at rather long scanning times. The active sensors offer higher scanning speed and work independent of in- and outdoor conditions. However, due to the monostatic geometry it is much more difficult to detect and image concealed metallic or non-metallic objects with an active scanning system. In this configuration an overlaid optical image has to help for concealed weapon detection.

5. ACKNOWLEDGMENTS

We would like to thank the Fraunhofer Institute for Applied Solid State Physics (IAF) in Freiburg, Germany, for providing us with their 220 GHz low noise amplifier technology.

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