Inspection of Samples using a fast Millimetre Wave Scanner

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Abstract. Millimeterwaves and terahertz sensors can cover a broad field of applications ranging from production control to security scanners. The outstanding features are the transparency of many materials like textiles, paper and plastics in this frequency region, the good contrast of any humid or dense dielectric material and the capability to employ miniaturized RF systems and small antenna apertures or dielectric probes. A stand-alone-millimetre-wave-imager, SAMMY, was developed and built, to demonstrate the outstanding features of this part of the electromagnetic spectrum for material inspection.

1. Introduction
Millimetre waves and the lower Terahertz region exhibit very good penetration capabilities for any type of dielectric material. Especially security applications demand such features for scanner technology against persons carrying hidden threat objects like weapons and explosives [1] or for the inspection of parcels and letters. Millimetre wave technology can be much cheaper and is completely free of radiation hazard in comparison with available x-ray technology. Moreover a considerably better contrast can be achieved for glass-like or dielectric material as well as for explosives. The same technology can also be used for quality control of food within its package as long as it is non metallic or for bulk material characterization, e.g. on a conveyor belt with recycling material. As a first step in the development of a millimetre wave based high speed inspection system a miniaturized stand-alone scanner operating at 77 GHz was developed and tested for several inspection applications.

2. Millimetre Wave Scanner Concept
The scanner should allow the non contacting detection of inhomogenities in dielectric material. Quasi transparent samples are inspected in transmission geometry at a frequency of 77 GHz. The scanning is achieved mechanically by rotating probes. The transmit-receive circuits are based upon commercial millimetre wave integrated circuits from automotive applications. Steering, data acquisition and quick-look evaluation is done by FPGA based electronics built into the compact apparatus. Further evaluation can be done on a PC, which is linked to the scanner. Quick-look images are processed and depicted in two ways: The first gives the amplitude image for the relative attenuation in the sample, the second shows the phase. Very often phase changes are more significant if the dielectric constant of the sample changes locally due to a foreign object.
2.1. Mechanical Scanner Concept

The scanning devices are dielectric millimetre wave probes [2] positioned opposing each other on two rotating discs covering the scanning volume in between. The sample is positioned on a sample holder from plexiglass, which moves linearly through the scanning plane. During the circular scanning process each position of the sample holder and thus of the samples upon the holder plate is illuminated by the collimated millimetre wave beam. The total scanning area is 30 cm x 30 cm. Scanning time for this area is < 30 s, which is only limited by the mechanical constraints. From an electric standpoint of view, much faster scanning is possible. For a future development with endless scanning area a speed of 3 m / s is envisaged. As a further perspective the scanning discs can be equipped with more sensor couples to increase the scanning speed or to use different frequencies simultaneously, which may be of importance for material characterization. Figure 1 demonstrates the total mechanical set-up, figure 2 shows a part of the scanning disk.

![Figure 1. Illustration of the Mechanical Concept of the Scanner](image1)

Figure 1. Illustration of the Mechanical Concept of the Scanner

![Figure 2. Scanning Disk with part of mmW Hardware](image2)

Figure 2. Scanning Disk with part of mmW Hardware

It has to be noted, that all RF hardware is mounted on the two disks. IF signals and DC lines are coupled to the disks using rotary joints.

2.2. Millimetre Wave Circuits

Figure 3 shows a block diagram of the RF section. The transmission system is operating fully coherent at 78 GHz, which allows to evaluate the phase of the transmitted signal in addition to the attenuation. All signals are derived from a highly stable quartz oscillator to which phase lock oscillators are
coupled. The millimetre wave frequency is generated by consecutive doubling and tripling with adequate filtering of the sidebands and amplification. The phase comparison is done at the up/down-converted 13 GHz level.

2.3. Production Prototype

A production prototype was assembled and can be used for demonstration purposes. Figure 4 shows a photo of the prototype.
For the prototype a laptop is used instead of the embedded PC to give more flexibility for evaluation tests. The prototype has been tested for different applications like food chain control, letter inspection and quality control. It is fully certified concerning to electrical and mechanical requirements and electromagnetic interference.

3. Results

Typical Samples were scanned with SAMMY. Figure 4 shows an amplitude image of an envelope with gun powder and some metal screws. As the scanner has a fully coherent transmission system, it is also possible to extract the phase changes induced by inhomogeneities in the envelope. Figure 5 also shows the respective phase, which is unwrapped and coded into pseudo colours.

![Figure 4](image1.png)

**Figure 4.** Pseudo Colour Images for Attenuation and the respective unwrapped Phase for an Envelope

The content of the envelope is clearly visible, different materials can be discriminated. The phase image allows a considerable enforcement of border lines compared to the amplitude attenuation image. Figure 6 shows the scanning result for a chocolate bar containing some glass particles. Also for this object the phase image gives a much more detailed representation. The glass particles are very easy to identify.

![Figure 6](image2.png)

**Figure 6.** Pseudo Colour Images for Attenuation and the respective unwrapped Phase for Chocolate with Glass Particles
The SAMMY scanner could demonstrate, that it is possible to give a quite detailed analysis of envelopes for letter inspection purposes and also easily detect foreign particles within food packages. The instrument can be used as it is now for demonstration purposes and inspection in small quantities. The same principle can be employed also for bigger scanners, e.g. for parcel inspection. The frequency of operation allows the use of commercial mmW chips and microstrip technology. In principle also higher operation frequencies can be used, if necessary to gain a better contrast. Going to higher frequencies, however, would require classical waveguide technology, which is not a principle problem, because all RF parts are located on the scanning disks and only low frequency signals have to be transferred via the rotary joint.

References

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