

# Detection of non-metallic impurities and defects through radar measurements

Dirk Nüßler, Christian Krebs and Ralf Brauns

Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR  
Fraunhoferstraße 20, D-53343 Wachtberg

**Abstract** The detection of non-metallic impurities and defects during the production of food is a critical task for every inspection system. Through recall campaigns caused by the contamination of food during the production process can corrupt the good reputation of companies for a long time. To minimize the risk a huge number of sensor technologies is implemented. The spectrum of sensors starts from the optical region over sensors in the infrared region to x-ray systems. The main disadvantage of most of the systems is the inability to detect non-metallic contaminations inside a product. The paper describes the possibilities of modern radar systems to fulfill these tasks.

## 1 Introduction

For the surveillance of production process a huge number of different sensors and systems are today available. The spectrum of the sensors starts with a less or more simple measurement of the weight of the product followed by metal detectors. Camera systems in the optical or infrared region offers a wide spectrum of additional information and finally x-ray systems allow a view inside the product. A critical task for all of these sensors are non-metallic impurities inside a product. X-ray systems allows the detection of metallic and non-metallic impurities inside a product as long as the contrast between the product and the impurity is high enough. For those applications radar sensors working in the millimetre wave range offers an alternative to present systems. High frequency sensors have the advantage that many dielectric materials in the microwave and millimetre wave region are transparent. Based on the used frequency range, high frequency sensors could not

realize the same spatial resolution, like sensors which work in a higher frequency range with a shorter wavelength. The frequencies of interest are in the millimetre wave region starting at 30 GHz and ending around 100 GHz. Systems in the frequency range above 100 GHz are technically possible but economically unviable. For this frequency range three different types of radar systems are possible, continuous wave (CW), frequency modulated wave (FMCW) and stepped frequency radar systems. For the calculation of the material parameters we need the physical dimensions of the device under test (DUT) and the phase information. In Particular the phase information is an important information for the detection of impurities which have an equal attenuation coefficient like the ambient material. The ability to measure the phase allows high frequency sensors to detect inclusions which are even invisible for a regular x-ray system. Like other sensors high frequency systems have a weak spot. Electrically conductive coatings and materials with a high water concentration are not transparent for electromagnetic waves.

## 2 Measurement set-up

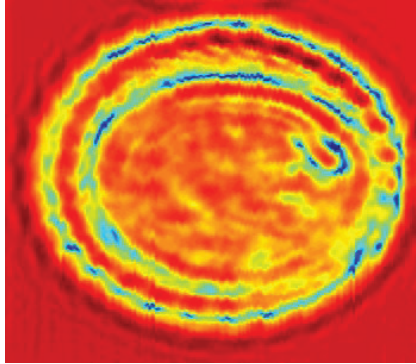
For the measurement set-up to main configuration are common. The simplest measurement configuration is a transmission configuration. Comparable to x-ray systems transmitter and receiver are on opposite sides with the DUT moved between. This configuration can be used for CW and FMCW systems. The second configuration is a reflection geometry with transmitter and receiver on the same side. This configuration is only for systems with a range resolution usable like FMCW systems. Both configurations have advantages and disadvantages, but from a more economical view CW systems can be realized much cheaper than systems with a range resolution. For every measurement system the antenna configuration is an important device. There are several possibilities to realize a compact configuration with a high resolution. Based on the system approach and the signal processing small antennas like open waveguides or patch antennas with small lenses are used or rectangular antennas in combination with a focusing lens. The pixel resolution depends on the selected wavelength, comparable to the optical region the resolution is approximately between 0.5 and 1 wavelength. Through the chosen wavelength of maximum 100 GHz with a wavelength of 3 mm,

the resolution is limited in millimetre wave region. For many industrial applications this resolution is insufficient. To realize a resolution better than 1 mm, we need a more sophisticated concept. One alternative is the use of near field probes for the measurements. With near field probes theoretical resolution better than 1% of the chosen wavelength can be realized. The biggest drawback of a measurement system with near field probes is the short measurement distance between the probe and the DUT. Depending on the measurement principal, resolution decreases when the distance between probe and DUT increases. For the performed measurements dielectric tips were used. For this configuration a compromise between distance and resolution was searched. Measurements have shown a good compromise between resolution and distance for a measurement distance of 10 mm. The results in this paper were all measured with a near field probe. Near field probes offer a good resolution in combination with a compact design for a low price and can easily be integrated in a high frequency system.

### 3 Measurement results

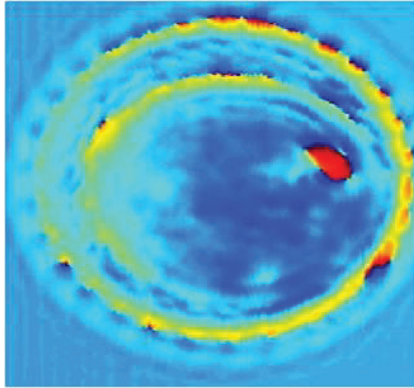
In a first step we compare the results of a amplitude measurement with a phase measurement. Amplitude measurements in the millimetre wave region follows the same restrictions like x-ray measurements. The contrast in the amplitude measurements is created through the different attenuation coefficient of the materials. Through the lower frequency range and the longer wavelength scattering effects appear which allows the detection of inclusions which have the same or an equal attenuation coefficient like the ambient material. There are many interesting research fields and over the last decade different applications were investigated and analysed. To find technology and economical successful applications for millimeter wave imaging systems, is the biggest challenge today. We need applications with a moderate number of systems, over hundred and not more than a few thousands, for a moderate price, over ten thousand but less than hundred thousand EURO, in a mass compatible technology like FMCW or better CW systems. Food industry is a perfect environment for radar sensors. The speed of production lines is moderate, typically not faster than 4 m/s and the products are normally typically well separated. Figure 14.1 shows a cookie which was pre-

pared for tests with a small piece of glass. Both glass and chocolate have a comparable attenuation coefficient in the measured frequency range. Through the scattering effects at the boundary between glass and chocolate the impurity can be easily detected. Unfortunately this effect is

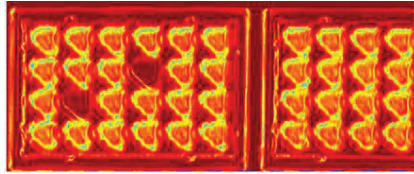


**Figure 14.1:** Picture of the amplitude measurement of a chocolate cookie prepared with a piece of glass.

only useable in a homogenous material. For cookies with nuts or other soughted ingredient, it is nearly impossible to separate desired from undesired components, when the attenuation coefficient and the physical dimensions are similar. We look again on our prepared chocolate filled cookie (Fig. 14.2). The phase measurements uses the dielectric properties of the material. Through the different material constant of glass and chocolate the runtime of the signal allows to discriminate between the two materials. In a CW system the different material parameters can be measured through the phase differences. The possible applications are not limited to the detection of inclusions and impurities inside of food. The measurements allows the detection of undesired defects in the production process. Through the ability to view through packaged products, defects like the missing pieces of chocolate in Fig. 14.3 can be easy visualized. Through the variation of the frequency range in combination with the phase measurement, the composition and concentration of ingredients can be controlled or the water content which could be an indicator for the freshness of a product. Especially in the production of food the humidity ratio or the concentration of ingredients should



**Figure 14.2:** Picture of the phase measurement of a chocolate cookie prepared with a piece of glass.



**Figure 14.3:** Picture of two packages of chocolate. On the left side two pieces are missing.

be constant. Through the comparison of the measured samples with a golden sample production processes can be monitored. As mentioned above radar measurements are sensitive to changes in the water concentration, many processes of maturing changes the water content inside the fruit which offers the opportunity to observe the degree of ripeness.

## 4 Conclusion

The ability of radar sensors to create high resolution images for quality control processes has been demonstrated. Through the combination of amplitude and phase measurements, high frequency sensors offer a wide spectrum of applications for the control of production processes

especially in the area of food. The sensors can be used in a transmission or reflection geometry and in contrast to other sensors like x-rays high frequency sensors combine the ability to transmit a product with non-ionizing radiation.