DOI: 10.58895/ksp/1000044906-19 erschienen in:

OCM 2015 - 2nd International Conference on Optical Characterization of Materials, March 18th – 19th, 2015, Karlsruhe, Germany : Conference Proceedings

DOI: 10.58895/ksp/1000044906 | https://www.ksp.kit.edu/site/books/m/10.58895/ksp/1000044906/

High frequency line cameras for sorting applications

Dirk Nüßler, Paul Warok and Nils Pohl

Fraunhofer FHR
e-mail: {dirk.nuessler,paul.warok,nils.pohl}@fhr.fraunhofer.de

Abstract The increasing number of multilayer structures in sorting applications or the detection and analysis of internal areas in products demands a cheap, safe and fast imaging technology. States of the art are x-ray systems especially for the inspection of food and heat flux thermography for the analysis of invisible defects under the surface. Inspection systems based on these technologies offer many advantages like the transmission through conducting materials, good resolution etc. Unfortunately they share a disadvantage. Based on the detector lines inside these camera systems or the time constant for the heat flux the maximum belt speed is limited. High frequency sensors offer the possibility to measure the transmission through non conducting materials without this hard limitation in speed.

Index Terms—THz imaging, millimeter wave radar, high speed inspection

1 Introduction

High frequency sensors allows a view inside the most non-conducting materials and products. With a typical wavelength between 10 cm and 1 mm the resolution is limited by the chosen frequency range. In the longer wavelength region the transmission through wet materials like fruits or complete walls is possible, but the resolution is very poor. In the higher frequency range the systems reaches a sophisticated resolution but the attenuation through water inside the products rises. The dynamic range of a high frequency system can be limited by many factors. E.g. an A/D converter can decrease the dynamic range despite the dynamic range of the system is much higher. Line cameras can be realized in transmission and reflection configuration and are separated in continuous wave (cw) systems and systems which offer a range resolution. System with a range resolution uses most times a frequency-modulated or pulsed signal. For the system approach a stepped frequency method (SFM) was chosen because it offers the best tradeoff between a low power sensor and high resolution concept. For the realization of a line camera modern radar technology offers a wide spectrum of several frequencies which can be used. System designs from the lower microwave region up to the THz region are possible. From a more economic point of view the best compromise between costs and resolution can be realized in mm-wave band between 30 GHz and 300 GHz. In the frequency range above 2 THz solid state materials have characteristic absorption lines which can be identified by a recognition algorithm. Without absorption lines a standard finger print analysis is not possible. The change of the dielectric properties over the frequency range is another approach to visualize the differences in the materials (Figure 19.1). As long as the number of different plastics is very low it's rather straight forward to identify materials through simple look-up tables. Real materials show a large diversity due to additives like flame retardants, plasticizers, UV resistance and aging effects. Therefor more versatile classification methods are recommended. In a first approach, methods based on Gaussian Mixture Models (GMM) and a Universal Background Model (UBM) were used. Using the Hilbert envelope of various band-filters, the amplitude and the time-position of the signal peak was extracted as features for a GMM-UBM system.

Photonic THz spectrometers offer the possibility to sweep over a large frequency range in a few milliseconds. Unfortunately, these systems are expensive and to slow for line arrays in a production line with a typical belt speed of 3 m/s. THz Systems based on cheap frequency multipliers are faster but they are working with a smaller frequency range. They could be used for industrial issues if the range is sufficient. Publications in the last years demonstrate the possibility to separate different plastics through their frequency response in the lower THz region [1]. These systems offer the possibility to measure the dielectric properties of non-conducting materials. The change of the properties over the frequency range allows the identification and classification of black plastics (Figure 19.2). To choose the optimum frequency range, the selected machine learning algorithms were trained with test data sets. In a second step a

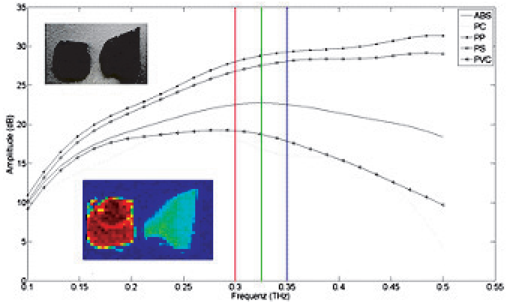

Figure 19.1: Measured results of two different pieces of plastic. In the image the differences between the three frequencies (300 GHz, 325 GHz, 350 GHz) are colorized.

blind test was performed. The lowest frequency range with sufficient results was the W-Band from 75 GHz up to 110 GHz. With a limited number of classes, test sets and a first prototype algorithm a probability between 85% and 90% for identification were realized. Based on these results a decision was made to realize a first test system in the lower THz region [2]. The mm-wave band offers a sufficient resolution for most applications and allows the realization of radar pixels on a printed circuit board (PCB) or on a silicon germanium (SiGe) chip. For the first realization step a sorting application was chosen. In recycling applications sorting machines for plastic uses hyperspectral cameras which measure only the attenuation of the reflected signal. These optical sensors are not able to sort black plastics, due to the reflected light from the black surfaces is too low for a stable detection process.

2 System Concept

To cover the whole width of a conveyor belt a great number of channels is necessary. To reduce costs system concepts with a limited bandwidth are preferred. The main disadvantage of systems with a small bandwidth is the poor range resolution. For a reliable parameter reconstruction algorithm the accurate height information is an important criterion. To compensate this disadvantage the high frequency line camera is combined with an optical height measurement system like a light section

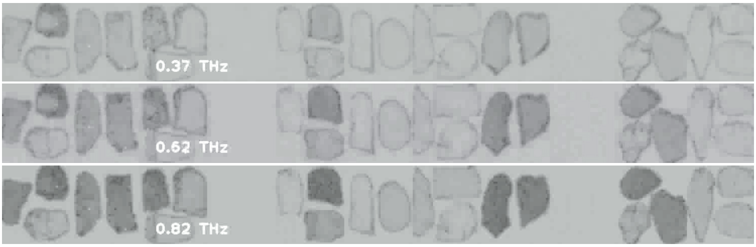

Figure 19.2: Measured attenuation for pieces of plastic for different frequencies in the lower THz region.

sensor or time-of-flight camera (ToF camera). The combination of these two technologies offers a cheap, fast and efficient system concept. The main challenge is the development of cheap high frequency channels in the frequency range above 75 GHz. Modern SiGe technologies seem to be well-suited for the development of line cameras for sorting applications. Their higher yield particularly for more complex chips with a higher number of transistors and the lower price makes this technology attractive. To design a system either focusing lens systems or open waveguide antennas as soon as dielectric tip antennas could be used. Depending on the cost, the resolution and the mechanical integration, open waveguide antennas and dielectric tips offers the best alternative for transmitting and receiving antennas above and under the belt. For a 300 mm width of the conveyor band a minimum number of 31 T/R modules are needed for a pixel width of 10 mm. Resulting in an aperture height for the transmitting antennas of 40 mm above the conveyor band. The transmitter channels are mounted above the band-conveyor. The receiver channels and the digital back-ends are installed under the conveyor belt. To minimize the number of active channels a switch matrix can be used to change one transmit/receive channel between different antenna positions. For the first prototype, a 90 GHz radar module is chosen (Figure 19.3). The system based on a 30 GHz radar module. Due to the tripled operation frequency a radar system with 12 GHz bandwidth from 84 GHz up to 96 GHz is realized. Based on the velocity of the conveyor belt with 3 m/s an update rate of 1 ms per channel is necessary.

Figure 19.3: Block with 4 transmitting channels.

The radar system can be used in different measurement modes like frequency modulated continuous wave FMCW, continuous wave CW or SFM. The frequency generation is based on a direct digital synthesizer (DDS). For the frequency reference a temperature stabilized quartz oscillator with high phase stability was chosen. The system concept demands a precision phase control across the frequency band. The controlling unit of the system is based on a FPGA. Each module of eight channels will be controlled by one Spartan 6 FPGA (DDS, ADC, etc.). A Master Unit with a Virtex FPGA (Virtex 6 Xilinx) combines the measured data and sends them via a Content Addressable Memory (CAM) interface to a Signal Processing Unit (SPU) which provides the measured results. Based on the limited space, the system is build up in a multilayer block structure. Power supply, digital-backend and the eight front-end channels are realized on separated layers (Figure 19.4-19.6).
The antennas mounted in the system are dielectric waveguides with their tips cut in an appropriate angle [3]. The outer dimensions correspond to the inner dimensions of classical waveguides. In the design a rectangular waveguide for the W-Band (frequency range from 75 GHz

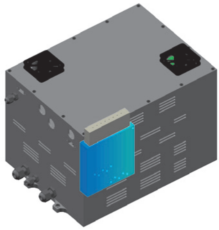

Figure 19.4: Complete receiver block

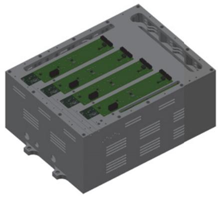

Figure 19.5: One of the two high frequency layer with 4 channels

to 110 GHz) was used with the dimensions 2.54 mm to 1.27 mm. Angle and length of the tips determine the gain of the waveguides, similar to horn-antennas (Figure 19.7). The advantage of this kind of antenna is the flexibility of the waveguide. As the wave is guided mostly outside the waveguides, the antennas are placed very carefully to avoid any contact with other parts of the measurement system. To protect the dielectric tips are covered with a Styrofoam radom.

For a waveguide junction a minimum space of 10 mm up to 20 mm is required. Test measurements and simulations have shown, that a minimum distance of two wavelengths between neighboring dielectric waveguides is necessary to reduce coupling effects. Based on this space requirements it is possible to arrange the antenna elements side by side. For future arrays smaller measurement distance are necessary. For theses arrays the coupling effects between the antenna elements can no longer be ignored. To solve this problem the antenna elements are build-

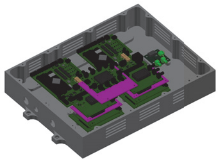

Figure 19.6: Digital backend layer

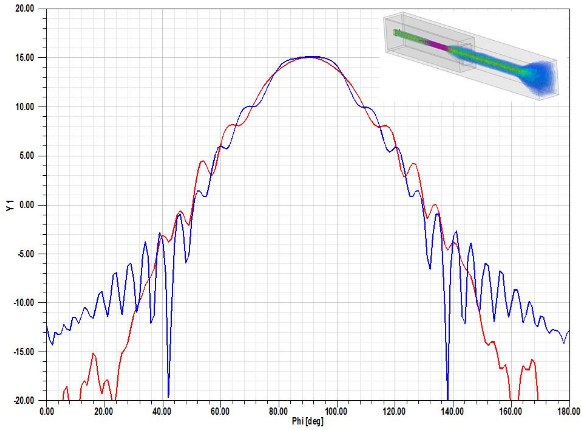

Figure 19.7: Antenna characteristic of the dielectric tips for the E- and the H-plane.

up in four independently lines. Through the different lines the spacing between neighbored antenna elements can be increased.

3 Outlook and summary

The combination of optical sensors with a THz line array in the lower THz frequency range seems to be a promising approach to sort black plastics. To realize the high requirement for a 100% recycling cycle a sophisticated signal processing is needed. The first measurements show a high accuracy. Under consideration that a non-optimized software algorithm was used the results show a high potential for future developments and are a good basis for the development of a high frequency line array for sorting applications.

References

1. Yun-Sik Jin, Geun-Ju Kim, Seok-Gy Jeo, "Terahertz dielectric properties of polymers," in *Journal of the Korean Physical Society*, 2006.
2. K. Hein, D. Stein, M. Stadtschnitzer, M. Demming, J. Küls, "Classification of polymers using gmm-ubm on high-frequency data," in *Sensor-Based Sorting*, 2014.
3. J. Weinzierl *et al.*, "Simulation and measurement of dielectric antennas at 150ghz," in *Proceedings of the 29th European Microwave Conference*, 1999.