Final Project Report:
Next Generation Ultra Wideband mm-Wave FMCW Radar for Industrial, Security and Life Science Applications

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***Abstract*—It was a great honor for me to receive the IEEE MTT-S Graduate Fellowship Award 2013 and I want to to take this opportunity to thank the whole MTT-S community for making the fellowship program possible and supporting young academics. The Graduate Fellowship had a big impact on my last year's activities. I was able to extend my research to new and interesting fields, and also got the attention of new industrial partners for supporting my future research work. This project report briefly summarizes the most important outcomes of my Graduate Fellowship Award project.**

***Index Terms*—Millimeterwave radar, ultra-wideband, SiGe bipolar ICs, fractional-N synthesizer, FMCW, vibration measurements, radar imaging, precision distance measurements.**

I. Introduction

GOAL of my Graduate Fellowship Award project was to evaluate the recent and upcoming advances in FMCW radar technology for its usage in industrial, security and life science applications. Due to the achievements in technology research nowadays semiconductor processes are achieving higher and higher f_T and f_{max}. This allows the design of highly integrated wideband FMCW radar systems in a frequency range up to the THz region with cost-effective and mass-production suitable sensor designs. Those systems are very interesting for many industrial applications like vibration measurements, highest precision distance measurements (e.g. machine health monitoring, online calibration, replacement for laser interferometers in rough environment applications, contactless vital sign monitoring, contactless gas pressure measurements) and of course imaging applications for production quality assurance (e.g. food security for frozen foods, detecting glas/plastic) and non-destructive testing.

My research plan for the IEEE Fellowship Award was divided into two main parts. One part is the FMCW radar sensor hardware to build a solid basis of high-end FMCW sensors for covering a wide frequency range of the millimeterwave region with an optimized performance for radar imaging, highest precision distance ranging and good stability for vibration detection applications. The other part is the evaluation of FMCW radar usage in new and emerging industrial applications, where former radar sensors were not accurate enough or too expensive and the upcoming advances in radar research show a big potential.

II. Hardware related research

Big steps have been made during the last year in the hardware development for new FMCW radar systems. The distance measurement accuracy and jitter of radar systems are depending on carefully designed systems with best characteristics in terms of phase noise, clock jitter and high quality IF digitalization. Two new radar backends have been designed. The first one (see Fig. 1) is a mid-end version with new features like backend synchronization capabilities for future multi-static FMCW radar measurement research. The other high-end backend consists of a Kintex 7 FPGA, DDR3 RAM and four 250 MSPS 16 Bit ADC channels and is planned to be used for phase coherent multi-channel radar measurements with highest precision and fast measurement rates. The use of the FPGA will allow realtime signal processing of all four channels. Two new mm-Wave wideband radar frontends have been developed, at 140 GHz for vibration measurements, and at 240 GHz for imaging applications. Additionally a miniaturized version of the D-Band radar based on a SiGe MMIC chip in combination with a mass production suitable waveguide transition is still under development and can hopefully be presented at the IMS this year.

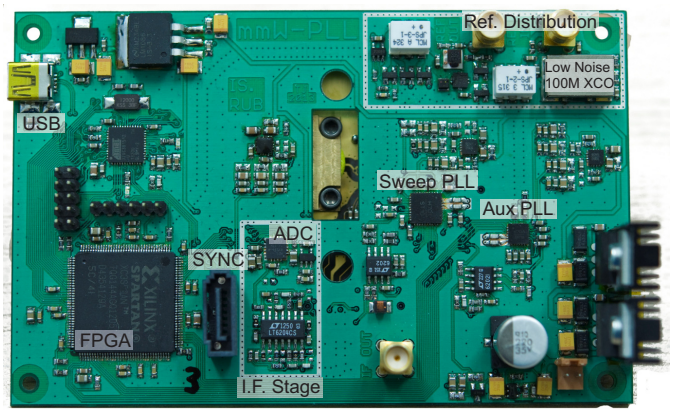


Figure 1. 122 GHz to 170 GHz D-Band FMCW radar backend with synchronization option for future multistatic radar research. More details will be published at the IMS2014 [1].

III. System and Application related research

My system and application related research focuses on the normal range measurements for highest precision distance and vibration measurements on the one hand, and imaging applications on the other hand.

A. Distance and Vibration Measurements

High precision distance and vibration measurements are an interesting application area for the upcoming industrial

FMCW radar generation. Many of these applications demand for micrometer accuracy and nanometer stability and right now expensive laser interferometers are used instead of radar. We recently reported in [2] that FMCW radar is also able to meet those requirements. At the IMS this year a new D-Band FMCW radar optimized for multi target vibration measurements and suitable for industrial high volume production at reasonable cost will be published. The sensor is very small (two stacked 3 cm x 4 cm PCBs), can be powered from USB, and will also be usable with Android tablets smartphones for data visualization. To cover new applications I also worked on contactless gas pressure and concentration measurements with FMCW radar, more details can be found in [3].

B. High Resolution Radar Imaging

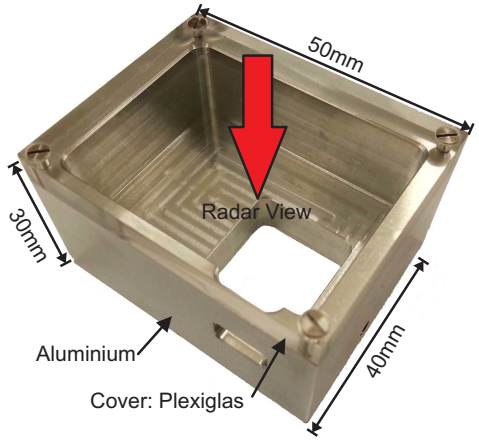
At the IMS2013 I presented 2D scanned images with a new 240 GHz wideband FMCW radar [4]. The beam of the on-chip antennas is focused and an object is scanned in the focal point distance. This system has the big disadvantage that it is only focused in one predefined distance plane. To overcome this problem I used the on-chip patch-antennas without any additional lenses and applied a 3D SAR processing to the collected datasets to obtain a 3D image which is focused in all distance planes. Figure 2 shows an animation of a scanned mini-radar housing made of aluminum with a plexiglas cover. For more information please have a look at my GeMiC2014 publication [5].

IV. IMS2013 Impressions

I really enjoyed my time at the IMS2013 in Seattle and being with the community for making new friends and to discuss the state-of-the-art research with other researchers from all over the world. I am also looking forward to the IMS in Tampa Bay this year, where I am presenting our new D-Band FMCW radar system for multi target vibration measurements. The technical program looks - like every year - very promising and I am sure that the long way to Tampa Bay will definitely be worth it. I can really encourage everybody to write papers for the IMS or at least attend to the IMS, it is every year a real highlight and an awesome time!

V. Conclusion & Next Career Plans

The Graduate Fellowship Award and especially the resulting financial independence really helped me to fulfill my ambitious research goals during the last year and I am sure that the award will also have a very positive effect on my future career. In the next two years I am planning to further advance my research on extremely high accuracy vibration and distance measurements for my doctoral (PhD) thesis. After finishing it I am strongly interested in continuing my career in an academic-close environment with good industrial connections, because I like the idea of transferring the new knowledge of emerging research fields from university to industry and generating benefits of this for both sides.



(a) Photo of a radar housing made of aluminium (3 cm x 4 cm x 5 cm) with a plexiglas cover.

(b) 3D SAR image animation of the object from (a) with 30 dB dynamic range and mm-resolution. It was scanned from the top through the plexiglas cover. To visualize the object the VisIt graphical analysis tool is used.

Figure 2. First 240 GHz 3D SAR imaging results. For more details please have a look at my GeMiC2014 paper: [5].

References

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