WADAPT

Minutes of the meeting, held at CERN, on 12 June 2015

Participants:

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The meeting started at 9 a.m. with a short introduction by E. Locci, reminding the goals of the meeting:

- Get together physicists/engineers interested in a common project of wireless readout (& wireless powering)
- Inform specialists of the wireless techniques of the context of HEP experiments.
- Inform engineers and physicists working on HEP experiments of the latest developments of wireless techniques and how they could be tuned for their needs.
- How to work together in the frame of a Collaboration for the benefit of all ? How to organize ourselves ? Plans ? Milestones ?

The meeting went on with formal presentations which were followed by discussions :

1. **Multi-gigabit wireless data transfer using the 60 GHz band** (H.K. Soltveit)

   After an introduction to the MM-wave band, its characteristics, advantages and practical opportunities, H.K. described its application in HEP, in the context of the ATLAS Silicon Micro-strip Tracker upgrade : a bandwidth of 100Tb/s, 20000 links at 5 Gb/s, without increasing material budget, power consumption, space for services, and contributing to the fast trigger decision (by topological radial readout). The 60 GHz transceiver chip was then described with its specifications : 57-66 GHz frequency band, 4.5 Gb/s data rate, OOK modulation, ~ 49 dBm minimum sensitivity, 10^{-12} BER, 250 mW power-consumption target, 10-100 cm transmission range. The chosen technology 130nm SiGe Bi-CMOS HBT 8HP allows a high integration level. The transmitter delivers necessary output power with high efficiency, high gain and stability. The receiver is designed to balance gain, linearity and noise figure (NF). The low-noise amplifier (LNA) is optimized for noise figure and gain, it sets the lower limit fof the system. The behaviour of the LNA has been simulated in forward reflection (input match), reverse reflection (output match), forward transmission (gain), reverse transmission (leakage). The double balanced mixer (DBM) is a frequency translation device that converts the signal from one frequency to another with the linearity required to handle amplified signals. The principle of passband modulation is to encode information into a carrier signal (60 GHz) suitable for tansmission. Using modulation is motivated by the simplification of the radiation of the signal and the possibility of having multiple radio-channel broadcasts. No modulation scheme possesses all the desirable characteristics : spectral efficiency, BER, signal-to-noise ratio (SNR), power efficiency, performance in multipath environment, implementation cost and complexity ; then some trade-offs are made when selecting modulation/demodulation schemes. Among the possible schemes having at least one of the listed characteristics (such as OOK, FSK, MSK, OFDM), OOK was retained at this stage for its low level of complexity. The filter design plays an important role in transmitters and receivers to remove out-of-band signal that otherwise would be modulated. The voltage-controlled oscillator is used to provide the reference frequency to modulate and demodulate the RF signal. The power amplifier (PA), designed for an output power of 5 dBm, has been simulated. The preliminary power-consumption estimate amounts to 190 mW half of which comes from the PA, however there is still room for improvement.

Antennas are passive components and do not generate power. The antenna is the largest part of the transceiver and its gain closes the link budget. The antenna is required to be light, compact, cheap, easy to fabricate and reproducible. The Uppsala university has started to design and produce patch antennas (see R. Brenner slides).

H.K concluded that MM-wave technology is a possible solution for current bandwidth limitations of LHC, and possibly other detector facilities. There is a lot of interest for this development. Three students from Bergen (ALICE) will join and the submission of a 60 GHz ASIC prototype in Heidelberg is planned for 30 November 2015.

Discussion :

Q *: How big the transceiver chip ?*
A *: About 25 mm2*

Q *: Is communication also needed from outside to inside the detector ?*
A *: It is not needed. It would be possible but would add complexity.*

C *: The submission of the draft for the prototype is foressen at the end of November, but there is no funding yet.*

2. **Wireless readout at 60 GHz – Feasibility studies for Particle Physics instrumentation**
(S. Dittmeier)

S. recalled the wireless readout concept for the tracking detector readout in the context of the ATLAS upgrade. The aimed data rate is 50-100 Tbps from about 20000 channels at 5 Gbps, with the constraints of minimized material, space, and power consumption. This goal can be reached with technologies at 60 GHz or higher frequencies. Some lab measurements were done in Heidelberg : data transmission, material properties, antenna characterization, cross-talk and link density, noise pickup in a detector module.

The detector module attenuates transmission of 60 GHz waves by more than 55 dB. 60 GHz signals were fully reflected, although diffraction lead to transmission near the edges of the tested module described in the slides. Ray tracing simulations were done and are reported in a thesis by T. Hugle. Crosstalk can be avoided using directive antennas, polarized antennas, absorbers of reflections, frequency channelling. A high limk density can be achieved with a link pitch smaller than 5 cm at a signal to noise ratio larger than 20.

The question of interference of the 60 GHz wireless with other detectors electronics was addressed by comparing the measured noise in readout chips with and without wireless transmission, and no significant effect was observed.

Discussion :

Q *: Is the flow of data continuous ?What about synchronization ?*

A *: Yes the flow of data is continuous and all detector elements get the same system clock and all data are given a time stamp that allows synchronisation between them by reference to the clock. This is true for any HEP experiment, independently of the chosen readout technique.*

Q *: Are losses of data acceptable ?*
A : *Data are always collected with an efficiency that is commonly larger than 99%. Systematic losses (local area losses) are more ennoying than random losses. Wireless readout has to be demonstrated as robust as any more conventional one.*

C *: The range of application is much larger than our show case. Fixed-target experiments have shown interest and one can easily imagine that wireless transmissions would be used when transmission must be done across vacuum.*

3. **Antenna for Gbit wifi data transfer in trackers**
(R. Brenner)

R. presented the future data challenges. In ATLAS the only subdetectors that are not used for fast trigger are the tracking detectors, and, to maintain current trigger thresholds at HL-LHC, the tracking detectors, being the most granular, can make this possible. This will require fast data transfer for short latency, matching with current trigger objects, high bandwidth transfer of large amount of data, possible data reduction on detector. Wireless would be an appropriate answer to these requirements. Wireless is mainly motivated by the reduction of dead material, the topological readout of the tracker and interlayer intelligence, enabling fast trigger and data reduction.

The work in progress encompasses the design and simulation of various antenna types suitable for usage in tracking detectors, their fabrication and characterization, preliminary radiation studies, their interconnection to transceivers with wire bonding, and the design of a demonstrator. The first irradiations with electrons of 5 MeV (100 krad dose), 120 MeV (100 krad and 10 Mrad) have shown no effect on capacitance for Dupont antennas whilst a small but sizeable effect has been observed with Rogers antennas. The interconnection studies have shown that the bond wire badly matches the antenna impedance; using an additional bond wire brought a small improvement (more wires does not bring additional improvement), but insufficient to achieve adequate matching. Some design and simulation studies for making a compensation circuit to improve the matching have been successfully tested. The first step of a demonstrator circuit has been achieved by attaching an antenna with a LNA, and in a second step and antenna will be attached to the transceiver developed in Heidelberg.

Discussion :

Q *: What is the length of the bond wire?*
A *: It must be less than 2 mm ; it is actually about 0.5 mm*

Q *: Have radiation tests been done with neutrons ?*
A : *Not yet. Actually the mecanism of radiations in real running conditions has to be understood and each component separately studied in appropriate facilities. Some tests in-situ can be done, at LHCb for instance, but the neutron flux is orders of magnitude smaller than at LHC. These tests could be done in ATLAS, but are not easy to perform.*

Q *: Is the dielectric the most sensitive material to radiations ?*
A : *All materials have to be chosen being radiation hard, but the whole design has to be tested for radiation hardness. In principle wireless systems are supposed to be the most radiation hard systems, and would be less problematic than optical systems.*

C *: There is a Radiation Working Group at CERN ; E. will contact them.*

Frequency shifts can be compensated, and are not a showstopper, however it is highly desirable not to have to compensate, in order to keep the system simple. Radiation hardness and system stability can be anticipated at the design level

4. **Mmw readout**

(C.Dehos)

C. showed millimiter wave current key applications such as Wireless HD and WLAN 802.11ad, backhaul and fronthaul, 24 and 79 GHz automotive radar. The CEA-Leti mmW portefolio includes frequency domain 60 GHz transceiver, time domain 60 GHZ transceiver and E-band backhaul with various ranges, data rates, power consumption and levels of maturity. These different domains were described in details. The lab possesses complete CAD design environment, can provide early access to Leti and ST technologies, test and characterization of chips and antennas, and is able to address manufacturability.

The ongoing developments include access point and backhauling in the frequency domain, as well as contactless connectors in the time domain.

The problematics of large collider detector readout was addressed with specifications and technical issues : important aggregated data rates (Tbps), important number of detector modules, crosstalks, signal confinment, liability in a harsh environment (radiations), low power consumption. Possible radio schemes were examined : layer to layer transmission (HU, low power short range transmission, time domain transceiver), gateway (aggregation of data, medium range high data rate transmission, frequency domain transceiver), wireless access point (multi user access scheme, very high data rate, frquency domain transceiver), data backhauling. Gateway is almost available now on the market, whilst other schemes are expected to be available within 2 years (5 years for the access point scheme).

The possible short-term contributions of CEA-Leti to the WADAPT project could be : architecture and system studies (characterization of the environment, modulation type evaluation, choice of carrier frequency vs application, system study and link budget, strategy for data treatment, system definition and specification, simulation), preliminary experimentation (measurement setup, propagation and channel sounding in a realistic environment, data transmission for proof of concept). The possible medium-term contributions could be : RF/mmW design (customization of existing 60 GHz chips towards LHC requirements, design of higher data rate transceiver), antenna/package design, prototyping. For both phases ressources and planning were evaluated, and funding hypotheses were made.

Wireless power supply was briefly discussed with the example of UHF (900 MHz) wireless power supply, RFID (13.56 MHz) with magnetic coupling. In the case of RF power transfer 50-100 mW could be obtained assuming directive antennas and high emitted power, e.g. with a small efficiency (~0.4% @ 4 m). Inductive coupling may have better efficiency but restricted to very short range 1-3 cm at 13.56 MHz (possibly longer range at 125 kHz).

Discussion :

***Q** : What means « expected commercial availability »?*
***A** : Many chips at 60 Ghz or higher frequencies at now available as prototypes, but are not massively produced at industrial cost. Prototypes can be used, tested, modified for HEP applications towards a selected package that can be massively produced. Once a package has been selected, at least 5 years are necessary to enter in the industrial production.*

***C** : In addition to reliability and cost, power consumption is an important issue ; an increase in power also translates into an increase in services.*

Higher frequencies such as 280 GHz are of great interest for HEP experiments as using them would facilitate the integration due to smaller size components and larger bandwidth availability.

5. **WADAPT Web site**
   (S. Ceuterickx)

   S. made the peleminary design of a WADAPT site (https://espace2013.cern.ch/wadapt/default.aspx) where we can put our documents and references, our tasks, our calendar, the collaboration members coordinates, post questions/answers. It would also be useful to link our indico agendas.
   Unfortunately S. is not working with CERN anymore and is thus unable to maintain/develop this useful site. We need to find a webmaster !

The meeting concluded with a general discussion.

6. **WADAPT Draft**

   Richard agreed to give his contribution by the end of next week and the draft should be available soon after an iteration. The draft will be posted on the WADAPT site and on archive to make it publicly available.

   More people around us are interested. One exemple might be the Cerenkov telescope array that could benefit from wireless to get rid of long cables. The engineering department at CERN has also shown an interest.

In wireless technologies particle physics is far behind industry, as there is certain conservatism in our field that is mainly due to the need for robust technologies in hardly accessible experiments. An example of a more accessible experiment is LHCb, which, coming a bit later than the other LHC experiments, used more advanced technologies. There is always great benefit in working at technology frontier and we need to catch the interest of developers working on upgrades or on future experiments. ATLAS is a kind of pioneer in using wireless techniques, but future applications should not be restricted to our domain.

HEP domain has no experience on wireless techniques and our community has to get informed and used to that. They can be informed in conferences and seminars. H.K. will present the chip in a conference, but at one point one should also talk about the project. However the project is somewhat too generic at the moment and a demonstrator needs to be built, which can be handled to people that could play with it, try it in their detector. In order to make people understand that wireless readout is not an utopia, our colleagues from CEA-Leti are the best partners to present future prospects not only at 60 GHz, but also at higher frequencies, in our context : chip design layout, system integration (some work has been done at 60 Ghz, but some work is needed at higher frequencies), system design. For example the question of modularity, interfaces has to be adressed. Now most detectors want to use the GigaBit transceiver architecture and transmission protocol, and will ask about the compatibility of a wireless system with GBT, and our colleagues from CEA-Leti will figure out how to make something compatible. One may also ask about the possibility of integrating wireless system with GBT in a single package. To demonstrate the viability of wireless in this context, some work is needed which requires manpower. Some interest has been manifested outside of our small group however there is a difference between being interested and being committed. The first step towards turning interested people into commited people lays into education, and it was felt that our colleagues from the CEA-Leti are the right persons to give seminars at CERN, CEA-Saclay, etc…

7. **Organisation**

Before having a demonstrator, it might be premature to divide tasks. Most of us cannot be fully commited to the wireless project as they are already committed to some other projects. Thus it would be good to have a research project for a student in each of our labs. With a full-time person in each lab, the project would be boosted. Cross-disciplinary projects would be an excellent way to get funding.

We will need another document to complement the WADAPT draft, that might initially be a simple page to define the tasks, the needed ressources. This page might be regularly updated. 60 Ghz re-designing for our applications could be done without to much effort, and many questions at 280 GHz could be answered at 60 GHz ; irradiation is one issue that could be addressed by some tests in some irradiation facilities, as CERN PS for instance.

We should have regular Collaboration meetings 2 or 3 times a year, but we may have meetings in between whenever needed. Our next meeting will be planned in October. This meeting should focus on higher frequencies that would give interesting projects for engineers.

Some milestones could be : Demonstrator of the chip designed by H.K., modification of existing circuits from CEA-Leti, GBT matching.

For the steps towards an « official » Collaboration, one key is a group which is knowledgeable in the wireless techniques, such as the CEA-Leti, being able to evaluate how high RF might work in our environment. The project has to be interesting enough for fundamental aspects to be investigated in the frame of a R&D Collaboration.