4 FINAL DEMONSTRATOR DEFINITION

The GRETA final demonstrator will take advantage from the available instruments at the laboratories of the consortium partners. Specifically:

University of Bologna

Available measuring equipment:

- Milling Machine LPKF ProtoMat E33;
- Spectrum Analyzer Agilent N1996A HP (100 kHz-6 GHz);
- Vector Network Analyser Agilent N9923A FieldFox (6 GHz) equipped with a 85521A calibration kit;
- Wideband Antenna HORN TDK (1-18 GHz);
- Signal Generator Hittite HMC-T2100 (10 MHz-20 GHz);
- Oscilloscope Tektronix TDS6604 (6GHz, 20 Gs/s);
- Arbitrary Waveform Generator Tektronix 7122C (12 Gs/s)
- Spectrum Analyze Hewlett Packard 8596E (12.8 GHz)
- Synthesized Sweeper Hewlett Packard 83752A (20 GHz)

University of Perugia

Available measuring equipment:

- 30 square meter clean room (1000 class under laminar air-flow);
- manual WEST-BOND wedge-bonding machine;
- semiautomatic ALESSI probe station equipped with micromanipulators, 50Ohm coplanar probes for on-wafer measurements up to 40GHz and CASCADE calibration substrate;
- Agilent E4407B 9kHz-26.5GHz Spectrum Analyser;
- Vector Network Analyser Agilent PNA N52230A 10MHz-40GHz equipped with a K coaxial calibration kit;

The final demonstrator will permit the test of the GRETA tag. The transmitter will be realized with an arbitrary waveform generator (AWG), emitting the UWB pulse sequence; the receiver front-end will be realized with an oscilloscope, sampling the signal received from the reader antenna; an UHF reader will interrogate the tag according to the Gen.2 protocol in the case of a hybrid UHF-UWB tag. Figure 71 reports the block schematic of such a test-bed configuration. The receiver will be emulated with Matlab, processing the samples acquired by the oscilloscopes for tag detection and ranging.

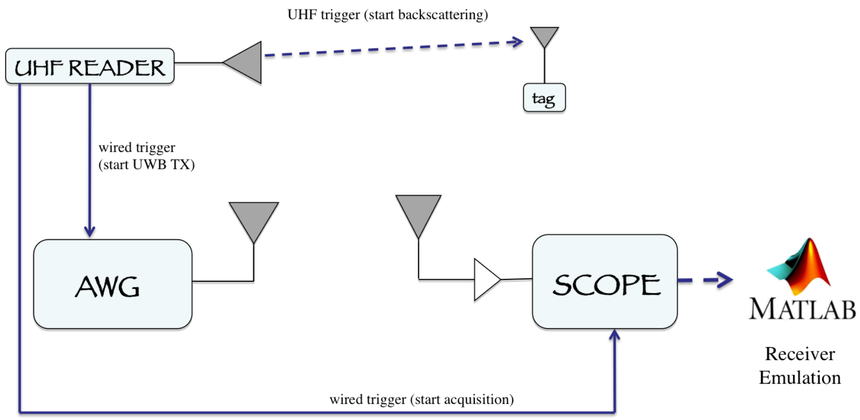

Figure 71: GRETA final demonstrator setup.

4.1 Preliminary GRETA Test-Bed

In order to test the tag UWB backscattering functionalities, a preliminary test-bed has been deployed at the University of Bologna. This test-bed version does not include the UHF Gen.2 compliant reader, but it is able to test the UWB backscattering communication capability. Figure 72 shows the principle adopted for the realization. A picture of the testing system deployed at the University of Bologna, Cesena Campus, is offered at Fig. 73

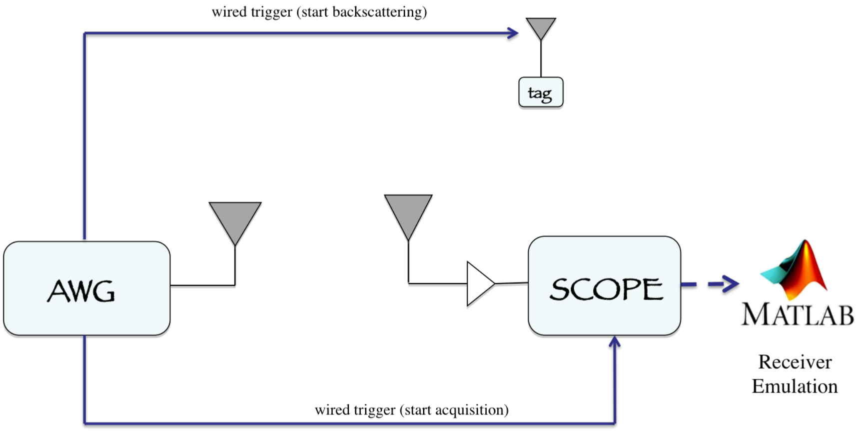

Figure 72: GRETA preliminary demonstrator setup.

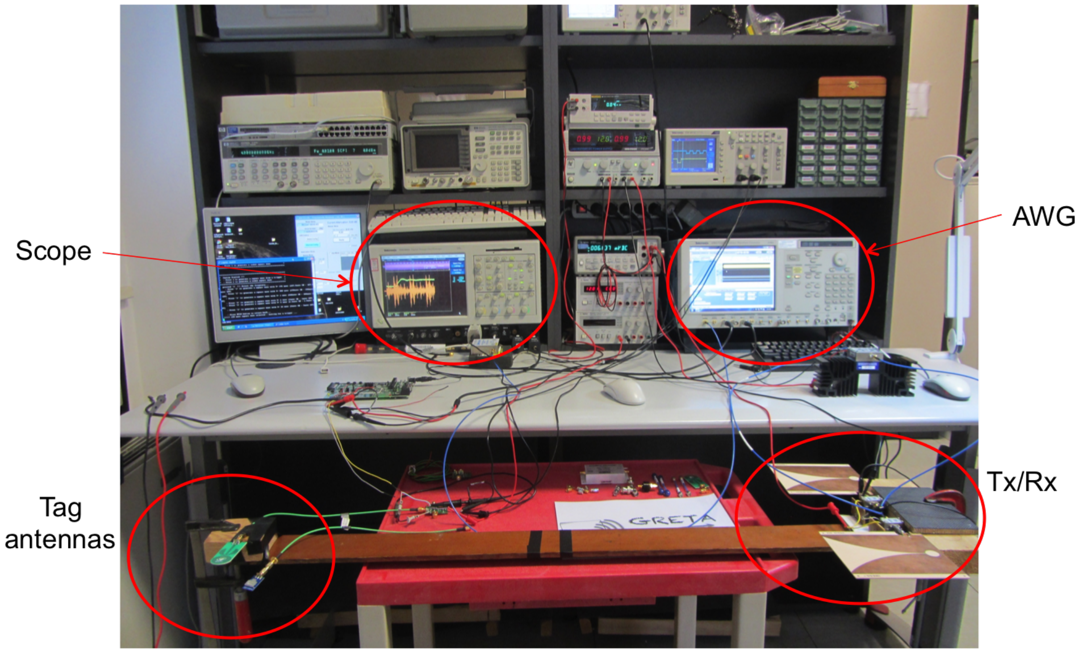

Figure 73: GRETA preliminary demonstrator setup at University of Bologna.

The AWG emits a sequence of UWB pulses and triggers the oscilloscope for starting the acquisition of the signal. The AWG output is connected to a UWB amplifier and then to a Vivaldi UWB transmitting antenna. A second Vivaldi UWB receiving antenna is placed in a quasi-monostatic configuration close to the transmitting antenna and collects the environment response. The signal received by the antenna is first amplified with a couple of wideband amplifiers and then recorded by the oscilloscope. The tag is composed of a Broadspec omnidirectional UWB antenna connected to a UWB switch. Such a switch links the tag antenna port to an open or short load according to a specific control signal. The control signal, built from the tag spreading code, is generated by a PIC micro controller board programmed for emitting it after the reception of a proper trigger from the AWG. In the final test-bed such a transmitter-tag synchronization signal will be obtained from the UHF carrier or from the interaction with the Gen.2 UHF tag subsystem. The transmitting and receiving antennas are shown in Fig. 74.

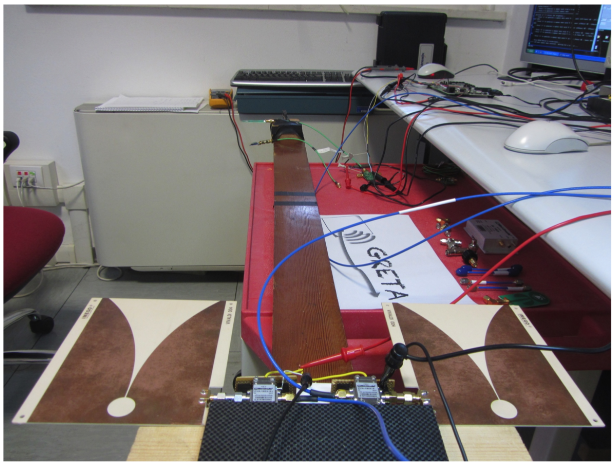

Figure 74: Transmitting and receiving antennas in a quasi-monostatic configuration.

4.1.1 Transmitter and Receiver Chain

4.1.1.1 Transmitter

The pulse train adopted as interrogation signal was built in Matlab according to the GRETA specifications in terms of central frequency and bandwidth. A root raised cosine (RRC) pulse centered at frequency $f_c = 4\,\text{GHz}$, with pulse width parameter $T_w = 1\,\text{ns}$ and roll-off factor $\beta = 0.6$, sampled at frequency $f_s = 12\,\text{Gs/s}$ was then imported by the AWG Tektronix AWG7122C.[1] Due to the reduced reader-tag distances considered, the pulse repetition period (PRP) has been imposed equal to 50 ns in order to enhance the transmitted power and to increase the number of recorded received waveforms, as detailed in the following. The amplitude of the transmitted pulse has been set equal to the maximum AWG analog-to-digital converter (ADC) range. The resulting pulse measured at the $50\,\Omega$ input port of an oscilloscope is reported in Fig. 75.

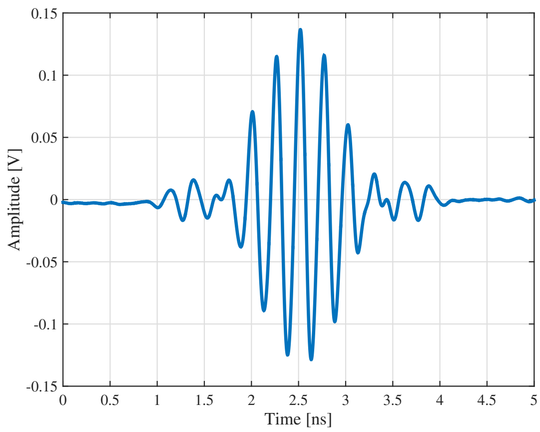

Figure 75: Trasmitted pulse.

Considering the PRP $T_p = 50\,\text{ns}$ the resulting PSD at the antenna port is reported in Fig. 76, where a comparison with the federal communications commission (FCC) mask and its limit of $-41\,\text{dBm/MHz}$ is offered. The pulse train presents a maximum PSD of about $-58\,\text{dBm/MHz}$ and a power of $-28.6\,\text{dBm}$. In order to have a suitable amplitude of the transmitted signal, the AWG output is then connected to a Mini-Circuits ZVA-183X-S amplifier with 26 dB gain, resulting in a $-32\,\text{dBm/MHz}$ PSD peak (9 dB

[1] The instrument has been equipped with an optional board in order to generate UWB signals.

above the FCC limit).[2]

4.1.1.2 Receiver Front-End

At receiver side, an oscilloscope Tektronix TDS6604 with 6 GHz bandwidth and 8 bits resolution operates as a front-end sampling the incoming signal at 20 Gs/s. A Vivaldi antenna collects the signal reflected by the environment and the tag. Such a signal is then amplified with a Mini-Circuits ZVA-183X-S amplifier (26 dB gain) followed by a Mini-Circuits ZVE-8G+ amplifier (30 dB gain). A variable attenuator Mini-Circuits RCDAT-6000-60 is adopted at the output of the amplifiers for adapting the signal to the oscilloscope dynamic. Due to the maximum record capability of 200 ksamples, only 10 μs of the received signal can be acquired and stored by the oscilloscope; this corresponds to acquire the response to 200 transmitted pulses with 50 ns PRP.

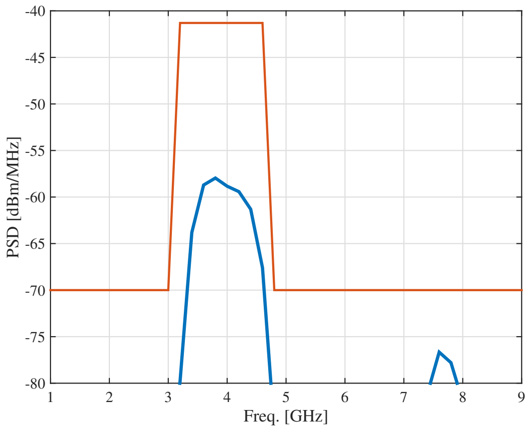

Figure 76: UWB tag realization.

Figure 77 presents a comparison between the reference pulse generated by the AWG, and the two pulses obtained at the output of the two power amplifiers considered, properly scaled and time-aligned. As it is possible to notice, the distortion introduced by the amplifiers is almost negligible[3]; this is confirmed by the cross-correlation coefficients between the reference pulse and the two amplified pulse, whose values are 0.96 for the ZVA-183X-S and -0.91 for the ZVE-8G+.

The described complete transmitter and front-end receiver chain is reported in Fig. 78.

4.1.2 UWB Tag Realization and Spreading Codes

The UWB tag has been emulated with discrete components by connecting several boards reproducing the final GRETA tag. First, an omnidirectional commercial UWB antenna Time Domain's BroadSpec has been adopted as tag antenna. Such an antenna has been connected to an Hittite 104122-5 switch board. Such a switch, with 6 GHz bandwidth, links the antenna port with two SMA ports, depending on the command signal; these two ports are connected to an open and a short circuit load, respectively, as depicted in Fig. 79.

The switch board is driven by a Microchip DM240312 development board for the PIC24FJ256DA210 micro controller. The micro controller is programmed for generating a control signal consisting of a sequence of alternating $+1$ and -1 chips at several working frequencies after the reception of a trigger command by the AWG. The available chip times are 250 ns, 500 ns, 1 μs, 2 μs and 5 μs. A switch loss of 4 dB was measured at the central frequency $f_c = 4$ GHz.[4] Fig. 80 shows the AWG trigger signal (a

[2] Actually, the FCC limit is imposed on the effective isotropic radiated power (EIRP) so the antenna gain in the maximum direction of the Vivaldi antenna should be considered.

[3] Notice that the 30 dB amplifier ZVE-8G+ introduces a sign inversion of the signal.

[4] Then, due to the backscattering mechanism, the switch loss on the tag signal is about 8 dB.

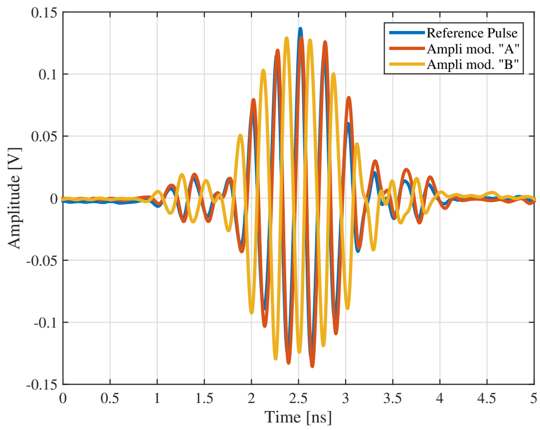

Figure 77: UWB pulse comparison.

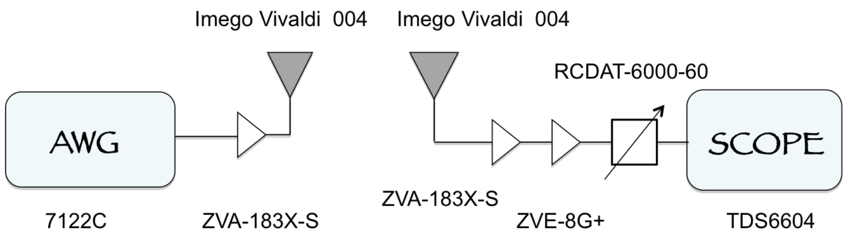

Figure 78: Transmitter e receiver chain for GRETA test-bed.

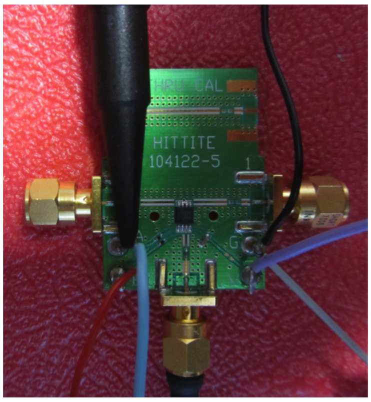

Figure 79: Tag switch board.

falling edge) and the switch board control signal as captured by an oscilloscope. Note that a delay of about 750 ns is present between the trigger and the starting of the tag modulation;[5] such a delay was compensated by properly timing the UWB pulses generation in the AWG. However, a jitter of several hundreds of nanoseconds is still present due to the elaboration of the trigger signal in the PIC board, and consequently a code acquisition stage must be accounted when processing the UWB received signal. In this first test-bed phase, such delay was characterized when collecting measurements and manually included in the processing algorithm.

The complete equivalent tag chain is displayed in Fig. 81.

[5]Here a chip time of 500 ns was considered.

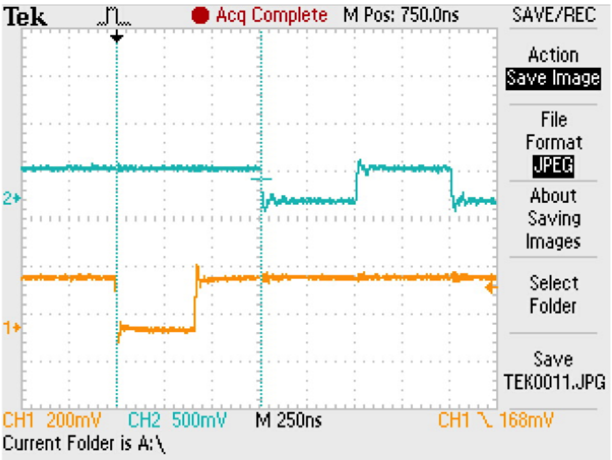

Figure 80: Switch board control signal.

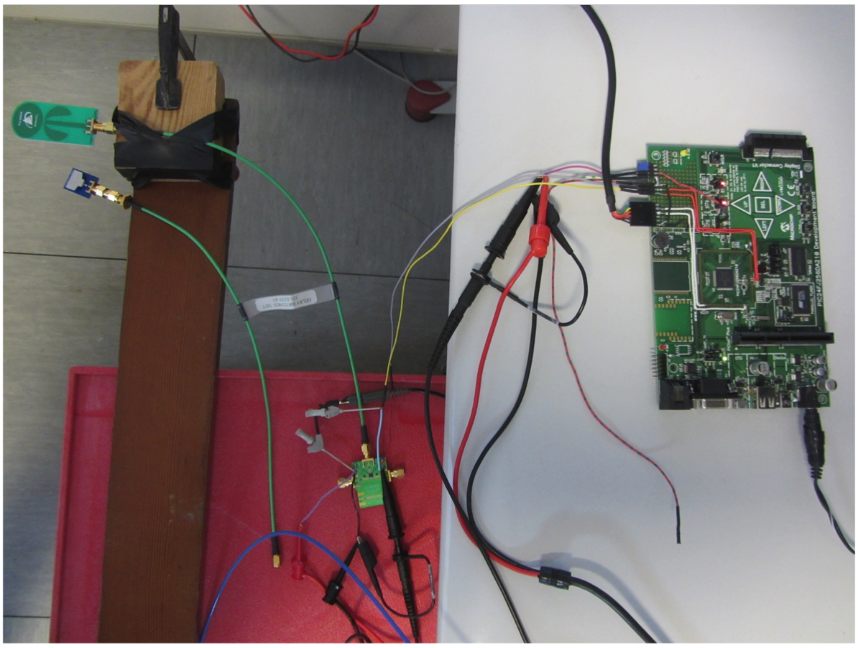

Figure 81: Equivalent UWB tag.
representative of the environment and of the reader position and orientation.

4.2 Preliminary Measurements

Measurements were conducted by acquiring the 200 ksamples available from the TDS6604 oscilloscope at the University of Bologna laboratories. Figure 82 shows an example of an acquisition where the channel responses to several transmitted pulses are plotted jointly with the tag's switch command signal collected with a probe.[6] Figure 83 shows the channel response to a pulse transmitted by the Vivaldi antenna and collected with an other antenna in the quasi-monostatic configuration. The overall acquired signal is composed of a series of 200 of these waveforms. The presented waveform encompasses the clutter (i.e., the environment response to the transmitted pulse given by the reflection of the walls, furniture and objects in the room) and the tag response (i.e., the antenna structural mode and antenna mode). In general the clutter can be considered almost constant between subsequent frames, while the antenna mode component changes according to the spreading code driving the switch in the UWB tag. In Fig. 83 it is possible to

[6] It is possible to notice the 250 ns chip time.

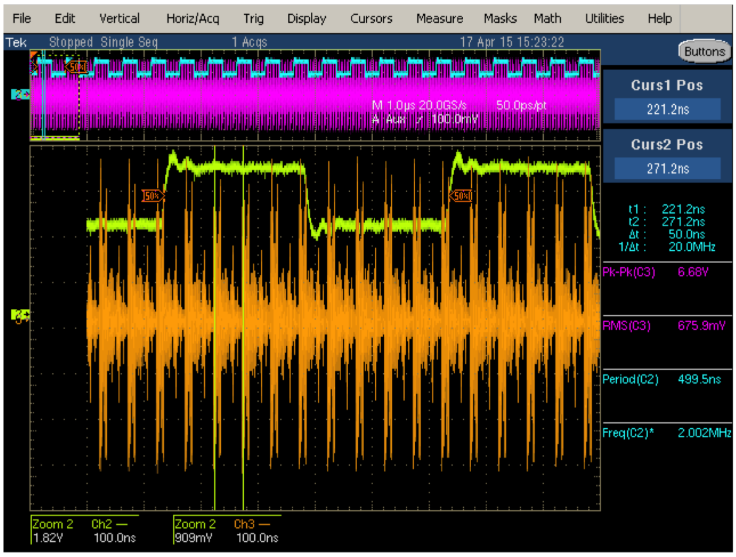

Figure 82: Example of oscilloscope capture.

notice the first big component of the response, that is the coupling between the transmitting and receiving antennas; then, a series of multipath components with different TOA are characteristic of the environment where measures are taken and of the antennas positions and orientations. In the presented measurements configurations the response amplitude is about 6 V_{pp}.

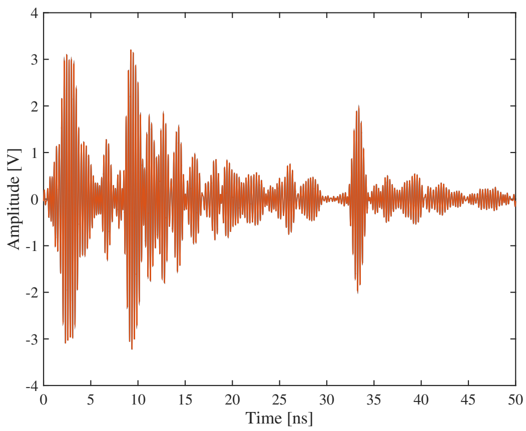

Figure 83: Channel response to a transmitted pulse.

In order to extract from the collected data the tag antenna mode component, which is modulated by the switch and then constitutes the useful part, a de-spreading procedure is necessary. Such a de-spreading consists in the multiplication of the overall response for a code equivalent to the one adopted at tag side (and synchronous with it). This is possible since the spreading code generated by the PIC board is known, and its delay with respect to the pulse sequence is measured with the instruments.[7]

Then, the resulting waveform after the code multiplication at receiver side is split in frames of length equal to the PRP T_p which are coherently summed up togheter. Since the tag code used at receiver is balanced (i.e., it is composed of the same number of $+1$ and -1) the result of such an operation is the cancellation of the clutter component which is constant between subsequent frames. Differently, the tag antenna mode component, which is modulated by the same code at tag side, grows and presents a process

[7] In the final version of the demonstrator such a code delay will be automatically recovered by the receiver with an appropriate code acquisition block.

gain of a factor N_s.[8] The result of such a de-spreading operation is shown in Fig. 84. As it is possible to notice, the tag signal TOA is different from the clutter signal TOA (which starts at the beginning of the windows with the antenna coupling) due to the distance between the transmitting/receiving antennas and the tag antenna. The estimation of such a TOA, which will be implemented in the following version of the GRETA demonstrator, will allow the tag's localization. Moreover, the channel profile of the tag response is different from the overall response of Fig. 83 due to particular tag position in the environment.

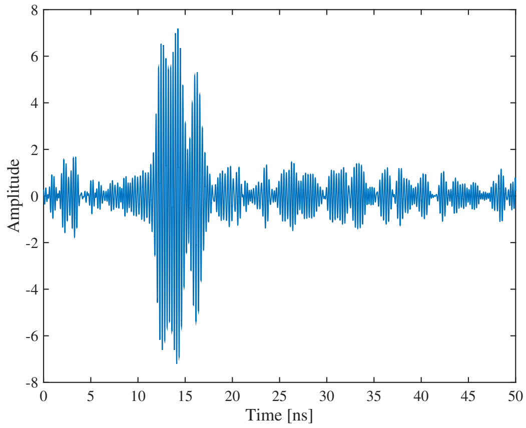

Figure 84: Tag antenna mode signal component after de-spreading.

In Fig. 85 the de-spreading result (in the bottom part) is compared with the results of a simple accumulation of the responses of Fig. 83 without accounting for the multiplication of the tag code (as usually done for active UWB signals to enhance the SNR without considering the de-spreading of the tag signal). It is possible to notice that, in the upper part, the output is a signal of peak amplitude around 600 (which is given by the 3 V peak amplitude of Fig. 83 and the summation of 200 pulses): such a signal does not contains anymore the antenna mode component which is cancelled by the summation due to the presence of a balanced tag spreading code. Differently, the de-spreading output consists in a signal of peak amplitude 6 (V); since the de-spreading signal also experiences a process gain of a factor N_s, this indicates that the tag antenna mode component in a single frame has a peak amplitude around 30 mV, which is about 20 dB smaller with respect to the clutter amplitude of 3 V peak. Moreover, this is the amplitude for a tag placed at about 1 m distance from the transmitting/receiving antennas, so farer tag will experience a smaller intensity signal. This fact highlights the need of adopting packets of several pulses length (e.g., $N_s = 10000$) in order to have a sufficient process gain for enabling the tag antenna mode component extraction from clutter and receiver noise.

In order to obtain an estimate of the tag antenna mode signal TOA for enabling localization, an energy profile can be built from the de-spreading output signal. The result, shown in Fig. 86 considering an integration time of 2 ns, is then processed for determining the tag signal starting point which gives the distance estimate.

[8]In such a scaled version we have $N_s = 200$.

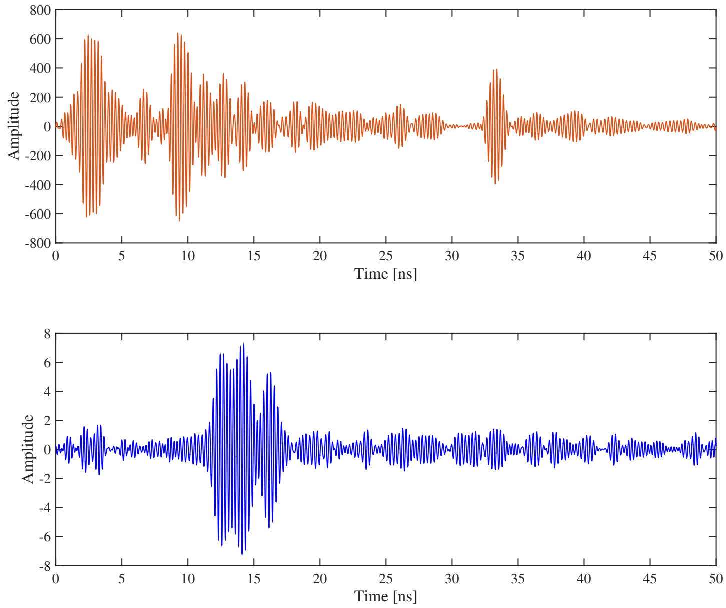

Figure 85: Comparison of the simple accumulation and de-spreading processing.

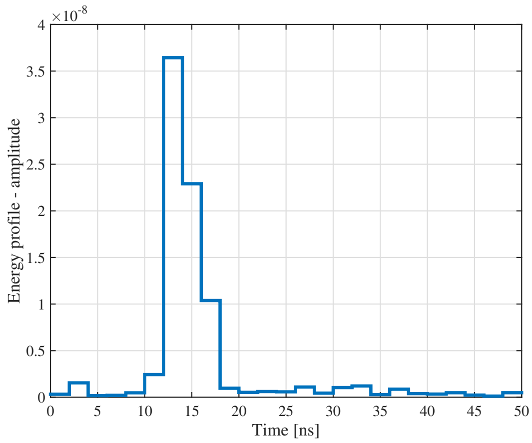

Figure 86: Energy profile of the de-spreading result.

5 DISSEMINATION ACTIVITY

In this section the dissemination activity carried out and planned by the research units is reported.

5.1 University of Bologna

The following papers have been published/accepted for publication and submitted:

- M. Dini, M. Filippi, A. Costanzo, A. Romani, M. Tartagni, M. Del Prete, D. Masotti, "A Fully-Autonomous Integrated RF Energy Harvesting System for Wearable Applications", Proceedings of 43rd European Microwave Conference (EuMC) (Nuremberg), 6-11 October 2013, pp. 987-990
- A. Costanzo, D. Masotti, "CAD Tools and Techniques for Co-Design of Multi-Source Energy Autonomous Systems", Digest of IEEE EuMC 2013 Workshop W03: Energy harvesting, circuit and system advances for battery-less Radio Frequency Identification (RFID) systems, Norimberga, October, 2013, pp. 1-30
- A. Costanzo, D. Masotti, T. Ussmueller, R. Weigel, "Tag, You're It: Ranging and finding via RFID technology", IEEE Microwave Magazine, July 2013, Vol. 14, No. 5, pp. 36-46
- A. Costanzo, D. Masotti, "Design of RF energy harvesting platforms for power management unit with start-up circuits", 13th International Conference on Micro- and Nano-Technology for Power Generation and Energy Conversion Applications (PowerMEMS), London, Dicembre 2013, pp. 1-5
- Masotti, D.; Costanzo, A.; Francia, P.; Filippi, M.; Romani, A., "A Load-Modulated Rectifier for RF Micropower Harvesting With Start-Up Strategies", Microwave Theory and Techniques, IEEE Transactions on , vol.62, no.4, April 2014, pp. 994-1004
- Costanzo, A.; Masotti, D.; Francia, P.; Fantuzzi, M., "Detection and movement estimation of items by a smart microwave hand-held reader," RFID Technology and Applications Conference (RFID-TA), 2014 IEEE , pp.214,218, 8-9 Sept. 2014, doi: 10.1109/RFID-TA.2014.6934230
- Trevisan, R.; Costanzo, A., "Exploitation of passive RFID technology for wireless read-out of temperature sensors", RFID Technology and Applications Conference (RFID-TA), 2014 IEEE , pp.150,154, 8-9 Sept. 2014, doi: 10.1109/RFID-TA.2014.6934218
- A. Costanzo, D. Masotti, "Object selection and detection by monopulse RADAR", Digest of IEEE EuMC 2014 Workshop WS6: Localization of energy autonomous devices, Roma, Ottobre, 2014
- R. Trevisan, A. Costanzo, "Contactless kW Power Transfer for Industrial Machines", Digest of IEEE EuMC 2014 Workshop WS3: Wireless Power Transmission Near and Far Field Approaches, Roma, Ottobre, 2014
- H. Visser, A. Costanzo, D. Masotti, "AntennaDesign forFar-Field WPT", Digest of IEEE EuMC 2014 Workshop WS3: Wireless Power Transmission Near and Far Field Approaches, Roma, Ottobre, 2014
- D. Masotti, V. Rizzoli, A. Costanzo, "Nonlinear/electromagnetic co-simulation of linear time-modulated arrays", Digest of IEEE EuMC 2014 Workshop WM5: Time as the 4th Dimension for Emerging Microwave Communication and Sensing Array Systems, Roma, Ottobre, 2014
- Costanzo, A.; Dionigi, M.; Mastri, F.; Mongiardo, M.; Russer, J.A.; Russer, P., "Rigorous design of magnetic-resonant wireless power transfer links realized with two coils," European Microwave Conference (EuMC), 2014 44th , vol., no., pp.414,417, 6-9 Oct. 2014, doi:10.1109/EuMC.2014.6986458
- Costanzo, A.; Dionigi, M.; Masotti, D.; Mongiardo, M.; Monti, G.; Tarricone, L.; Sorrentino, R., "Electromagnetic Energy Harvesting and Wireless Power Transmission: A Unified Approach," Proceedings of the IEEE , vol.102, no.11, pp.1692,1711, Nov. 2014
- D. Masotti, "Time-modulated arrays for smart WPT", oral presentation at 4th meeting of COST WIPE (action IC1301), Graz, 30-31 March, 2015
- F. Berra, A. Costanzo, M. Dionigi, D. Masotti, F. Mastri, M. Mongiardo, R. Sorrentino, "Antenna design for unified far-field communication and near-field recharging", accepted for publication at European Conference on Antennas and Propagation (EuCAP) 2015, Lisbon, April 2015
- D. Masotti, R. Marchukov, V. Rizzoli and A. Costanzo ,"Far-field Power Transmission by Ex-

ploiting Time-modulation in Linear Arrays", accepted for publication at Wireless Power Transfer Conference (WPTC) 2015, Boulder, May 2015
- M. Del Prete, D. Masotti, F. Berra and A. Costanzo, "Exploitation of a dual-band cell phone antenna for Near-field WPT", accepted for publication at Wireless Power Transfer Conference (WPTC) 2015, Boulder, May 2015
- M. Fantuzzi, D. Masotti, A. Costanzo, "Simultaneous UHF Energy Harvesting and UWB-RFID Communication", accepted for publication at International Microwave Symposium (IMS) 2015, Phoenix, May 2015
- M. del Prete, A. Costanzo, A.Georgiadis, A. Collado, D. Masotti, and Z. Popovic, "Energy-autonomous Bi-directional Wireless Power Transmission (WPT) and Energy Harvesting Circuit", accepted for publication at International Microwave Symposium (IMS) 2015, Phoenix, May 2015
- A. Costanzo, D. Masotti, "Wirelessly powering: an enabling technology for zero-power sensors, IoT and D2D communication", accepted for publication at International Microwave Symposium (IMS) 2015, Phoenix, May 2015
- A. Costanzo, D. Masotti, M. Del Prete, R. Trevisan, "Potential space applications of two far-field and near-field WPT systems", invited at International Microwave Symposium (IMS) 2015 Workshop WFK: New technology application for Space, Phoenix, May 2015
- A. Costanzo, D. Masotti, M. Fantuzzi, "RF-baseband nonlinear co-design of zero-power harvesting systems", invited at International Microwave Symposium (IMS) 2015 Workshop WFC: Nonlinear RFID systems, characterization and exploitation, Phoenix, May 2015
- R. Marchukov, D. Masotti, A. Costanzo, "Dynamic Wireless Power Transfer by Time-Modulated Arrays", accepted for publication at Antennas and Propagation Symposium (APS) 2015, Vancouver, July 2015
- M. Fantuzzi, D. Masotti, A. Costanzo, "A multilayer compact-size UWB-UHF antenna system for novel RFID applications" accepted for publication at European Microwave Conference (EuMC) 2015, Paris, October 2015
- M. Fantuzzi, D. Masotti, A. Costanzo, "A novel integrated UWB-UHF one-port antenna for localization and energy harvesting", submitted to IEEE Transactions on Antennas and Propagation

5.2 University of L'Aquila

The following papers have been published or accepted for publication:
- P. Di Marco, C. Fischione, F. Santucci, and K.H. Johansson, *Modeling IEEE 802.15.4 networks over fading channels*. IEEE Transactions on Wireless Communications, October 2014.
- N. Rendevski and D. Cassioli, *BER of IEEE 802.11ad OFDM Radios vs. Carrier Frequency in Real 60 GHz Indoor Channels*, ICC 2014, Sydney, Australia, June 2014.
- D. Cassioli and N. Rendevski, *A Statistical Model for the Shadowing Induced by Human Bodies in the Proximity of a mmWaves Radio Link*, ICC 2014 WS on 5G, Sydney, Australia, June 2014.
- M. Vari and D. Cassioli, *mmWaves RSSI Indoor Network Localization*, ICC 2014 WS on ANLN, Sydney, Australia, June 2014.
- P. Di Marco, F. Santucci, and C. Fischione, *Modeling anti-collision protocols for RFID systems with multiple access interference*, IEEE ICC 2014, Sydney, Australia. June 2014.
- R. Alesii, R. Congiu, F. Santucci, P. Di Marco, and C. Fischione, *Architectures and protocols for fast identification in large-scale RFID systems*, IEEE ISCCSP 2014, Athens, Greece. May 2014.
- P. Di Marco, C. Fischione, F. Santucci, and K.H. Johansson, *Effects of Rayleigh-lognormal fading on IEEE 802.15.4 networks.* IEEE ICC 2013, Budapest, Hungary. June 2013.
- M. Di Renzo, C. Merola, A. Guidotti, F. Santucci, and G.E. Corazza, *Error Performance of Multi-Antenna Receivers in a Poisson Field of Interferers: A Stochastic Geometry Approach*, IEEE Transactions on Communications, Vol.:61 Issue:5 Pag.:2025 -2047, May 2013.
- A. Guidotti, V. Buccigrossi, M. Di Renzo, G.E. Corazza, and F. Santucci, *Outage and symbol error probabilities of dual-hop AF relaying in a Poisson field of interferers*, IEEE WCNC 2013, April

2013.

- A. Falcone, L. Pomante, C. Rinaldi, and M. Santic, *Performance analysis of a lightweight localization algorithm for WSNs in a real scenario*, Signals, Circuits and Systems (ISSCS), 2015 International Symposium on, July 2015. (to be presented)

In addition, the following presentation is reported:

- D. Cassioli, *Millimeter-waves wireless communications*, XI International Conference ETAI 2013, Ohrid, Macedonia. 26-28 Sept. 2013. Plenary Talk.

5.3 University of Pavia

- R. Moro, S. Kim, M. Bozzi, M. Tentzeris, "Inkjet-Printed Paper-Based Substrate Integrated Waveguide (SIW) Components and Antennas," International Journal of Microwave and Wireless Technologies, Vol. 5, No. 3, pp. 197âĂŞ204, June 2013.
- S. Kim, B. Cook, T. Le, J. Cooper, H. Lee, V. Lakafosis, R. Vyas, R. Moro, M. Bozzi, A. Georgiadis, A. Collado, and M. Tentzeris, "Inkjet-printed Antennas, Sensors and Circuits on Paper Substrate," IET Microwaves, Antennas and Propagation, Vol. 7, No. 10, pp. 858âĂŞ868, July 16, 2013.
- S. Kim, R. Moro, M. Bozzi, S. Nikolaou, M. Tentzeris, "Inkjet-printed Wearable Microwave Components for Biomedical Applications," 7th European Conference on Antennas and Propagation (EUCAP 2013), Gothenburg, Sweden, April 8âĂŞ12, 2013.
- M. Pasian, M. Bozzi, L. Perregrini, "Radiation Losses in Substrate Integrated Waveguides: a Semi-Analytical Approach for a Quantitative Determination," 2013 IEEE MTT-S International Microwave Symposium (IMS2013), Seattle, WA, USA, June 2âĂŞ7, 2013.
- R. Moro, S. Kim, M. Bozzi, and M. M. Tentzeris, "Implementation of Substrate Integrated Waveguide (SIW) by Inkjet-printing on Paper Substrate," 34th Progress in Electromagnetics Research Symposium (PIERS 2013), Stockholm, Sweden, August 12-15, 2013.
- M. Bozzi, "Substrate Integrated Waveguide (SIW) Technology for the Next Generation of Microwave and mm-Wave Systems," 34th Progress in Electromagnetics Research Symposium (PIERS 2013), Stockholm, Sweden, August 12-15, 2013 (invited paper).
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- submitted paper to Journal of Low Power Electronics and Applications;

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