# An SDR Based Channel Sounding Technique for Embedded Systems

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***Abstract*—This paper presents a low cost OFDM based channel sounding technique which can be implemented on a low power embedded system. The technique is first used to measure the channel of an indoor environment and is validated by comparison with a VNA and a ray-tracing simulator. We then show its usage in two interesting situations. Finally, we conclude the paper by giving the advantages and drawbacks of the technique and propose some solutions for improvement.**

***Keywords—Channel measurements, OFDM, Embedded systems***

## I. Introduction

In the context of Internet of Things (IoT) wireless connected objects are expected to be operated in many different situations (e.g. factories, healthcare, etc.) and in many different environments. It is obvious that a wireless communication cannot be optimal in all situations. In some cases, it is necessary to obtain the wireless channel properties in order to be able to design a suitable communication system. For that purpose, one can resort to a channel sounding campaign using specialized and generally very costly equipment [1]. This is quite efficient but due to the size and weight of this kind of equipment, it cannot be carried everywhere. As we will see later on, this can really be a problem in huge hangars where planes are built like the ones found in the Airbus factory in Toulouse, France. Another more desirable solution would be to have a portable channel sounding solution without sacrificing too much the performance. Having such an embedded solution, for example integrated into a belt carried by an operator or on a small drone would present the advantage of a real time channel analysis helping the system to adapt to the wireless communication conditions. This is precisely the aim of this paper: to present and evaluate a channel sounding technique having low complexity and that can be implemented on limited power (energy and processing) embedded systems.

The rest of this paper is organized as follows. In the next section we give a brief overview of channel sounding techniques and present an OFDM based channel sounder suitable for embedded applications. Section III is dedicated to the validation of the method. Measurements performed in an indoor environment are compared to a classical VNA sounding system and also to simulations performed with a propagation ray tracing software. In section IV we present results obtained in several environments (static and moving). Finally, section V concludes the paper by presenting the advantages and drawbacks of the system while giving some options for improvement.

## II. OFDM Channel Sounding

### A. Channel sounding techniques

Basically, wireless channel sounding can be performed with any transmitter-receiver configuration. Wideband channel sounding techniques can be classified in frequency- and time-domain methods [2].

*Frequency domain methods* use tone stepping to sweep the RF spectrum of interest to obtain the channel transfer function. The most well-known setting using this method is the Vector Network Analyzer (VNA) which measures the magnitude and phase of the forward transmission gain $S_{21}$ between the transmit and the receive antennas. The drawback of this method is that tone stepping over a large bandwidth is slow and because of timing constraints, the measurements can only be performed through a wired system. However, this system provides a good multipath resolution and small storage requirements. To increase the speed of this technique it is possible to excite the channel with a swept frequency (chirp) signal or to use a multi-tone signal. This latter solution is used by the RUSK channel sounder which is one of the most evolved channel sounding system to date [1].

The starting point of *time-domain methods* is based on the impulse response of a linear system (i.e. the channel). In that case, the probing signal is a pulse of width $T_w$: the shorter the pulse, the larger the analysis bandwidth. However, this method is very sensitive to noise and interference and requires a high peak-to-average power ratio (PAPR). In practice, pulse compression methods are used to overcome the large dynamic range and also to reduce the sampling rate by compressing the wideband signal. These techniques use the property of the autocorrelation of white noise. Considering white noise as an input to the linear system, when the output of the system is cross-correlated with a delayed version of the input the resulting cross-correlation is proportional to the impulse response of the system $h(\tau)$. As white noise is difficult to

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generate, pseudo-noise (PN) maximum length sequences (MLS) are used in practice. The ultimate evolution of pulse compression methods is the swept time-delay cross-correlation (STDCC) based channel sounding technique. First used by Cox in [3], this method performs pulse compression by correlating the received PN sequence with an identical PN sequence clocked at a lower rate. It then allows reducing the sampling rate at the receiver thus reducing the recording requirements. Finally, there is an important point to mention about time-based techniques and this is the need for a very precise time clock (i.e. an atomic clock).

After this short review we present in the next section an orthogonal frequency division multiplexing (OFDM) based channel sounding technique suitable for embedded systems.

### B. *Using OFDM for channel sounding*

OFDM is used in many standards since it is a very efficient technique able to fight the detrimental effects of frequency selective channels. By sharing the transmission data rate on N subcarriers via orthogonal frequency multiplexing, it ends up with the channel seen as frequency flat from a subcarrier point of view. An OFDM system suitable for a time and frequency selective channel can be designed by using only the two simple following inequalities:

$$\Delta f << Bc \quad (1)$$

$$T_{S,MC} << Tc \quad (2)$$

$\Delta f$ represents the bandwidth occupied by a subcarrier and $T_{S,MC}$ is the time duration of the OFDM symbol. Bc is the wireless channel coherence bandwidth and Tc is the coherence time of the channel.

In a classical OFDM system using coherent digital modulation, it is necessary to have a mean of estimating the phase shifts induced by the channel. This is generally done by using pilots which are just digital modulation symbols known by the receiver. Optimum placement of pilots in the data has to conform to the Shannon-Nyquist sampling theorem in the frequency (subcarriers) and time directions (OFDM symbols). Now what about sending only pilots? By doing so, we create a channel sounding system which samples the channel in the frequency and time directions. Fig. 1 shows an example of the channel frequency response H(f,t) obtained by using this method. By using an IDFT operation on the frequency response, it is easy to get the channel impulse response (CIR) h(τ,t). This is the main idea of our channel sounding system. Let us now go into the implementation details.

### C. *An SDR based OFDM channel sounder*

- <u>Hardware: high-end equipment</u>

Fig. 2 shows that the channel sounder is built around two Ettus Research X310 high end Software Defined Radio (SDR) equipment [4]. Basically, an SDR equipment is made up of two main parts: an FPGA plus a digitization chain and a software configurable RF front end. The FPGA part connects to a computer via a high speed digital interface (GbE, PCie etc.). It communicates with the digitization chain so as to convert from the digital domain (PC to RF) to the RF analog domain (RF to PC) and vice versa. The RF front end role is to up-convert the baseband signal (transmission) or to down-convert the RF signal to baseband (reception). It takes the form of a daughter board plugged into the X310. Its frequency range is 1.2GHz to 6GHz. Table I summarizes the main characteristics of the SDR equipment used.

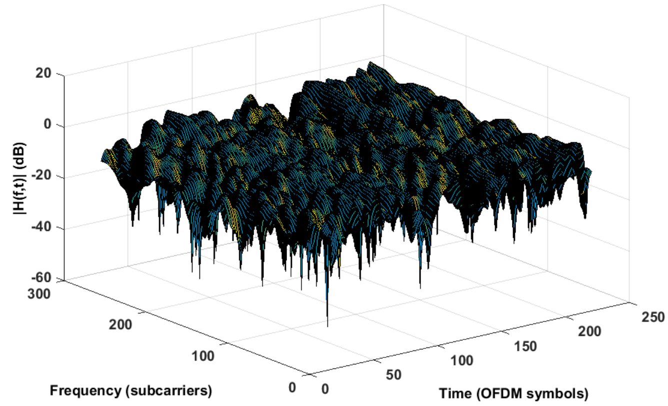


Fig. 1. OFDM channel sounding example.

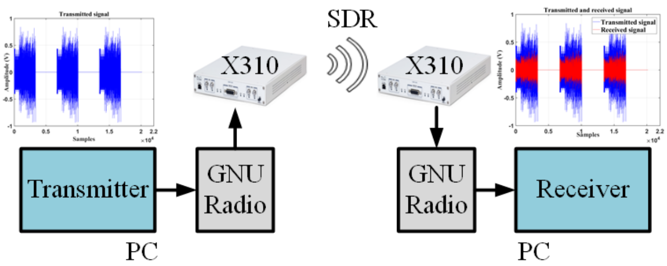


Fig. 2. OFDM channel sounder components.

As can be noticed from Table I, the digital communication with the PC takes the form of a 10GbE interface. This is a key point of high speed SDR equipment. Indeed, using a 1GbE interface does not allow the data transfer of sampling rates over 25MSps. This point is directly related to the resolution of our channel sounding system. As explained in the previous section, we ultimately want to obtain the CIR of the sounded channel. In order to resolve the main paths of a CIR the sampling frequency has to be quite high. At present, with this type of equipment, it is possible to reach a 100MSps sample rate yielding a 10ns delay resolution step which is compatible with indoor channels characterization.

- <u>Hardware: the embedded sounder</u>

Although it can be operated with laptops, there are a number of situations when it is not possible to use the full feature sounder presented before. We are going to show some of these situations in section IV. The first reason is related to the mains power needed by the X310 equipment which is not always available. The second reason concerns the size and weight of the equipment. For these reasons, we have looked for a small size and weight factor and battery powered solution. This can be achieved with the so-called SoC FPGA technology [5] which combines, in the same chip, a low power microprocessor tailored for embedded applications (low power) and an FPGA which allows to design high speed digital interfaces to wideband RF front ends. Ettus Research sells such a system called E310 but we have not been able to go over 8MSps which is too slow for our application. Using the same type of hardware but without the software layer from Ettus Research we have built a system around a SocKit FPGA board and an ARRADIO RF board from TERASIC [6] which features the AD9361 chip, a highly integrated RF transceiver from ADI [7]. To obtain the same transmit power as the PC based sounder we have added a +18dBm wideband MMIC amplifier to the system. With this system, weighting only 450g, we have been able to achieve transmission rates of 40MSps. Table II summarizes the main features of this system and Fig. 3 shows a picture of the system embedded on an hexacopter drone.

TABLE I. PC BASED SDR CHANNEL SOUNDER CHARACTERISTICS

| | |
|---|---|
| **Carrier frequency** | 1.2GHz to 6GHz |
| **Transmit power** | Up to +18dBm |
| **Data rate** | Up to 100MSps with 10GbE (50MSps laptop with PCIe X1) |

TABLE II. EMBEDDED SDR CHANNEL SOUNDER CHARACTERISTICS

| | |
|---|---|
| Carrier frequency | 70MHz to 6GHz |
| Transmit power | Up to +18dBm |
| Data rate | Up to 40MSps transmit rate |
| Power | 2200mAh 3S LiPo battery |
| Autonomy | 1h30mn |

Fig. 3. Embedded sounder on a drone.

- Software

As can be seen on Fig. 2, the OFDM channel sounder uses a packet mode transmission. The number of OFDM subcarriers used by the packet can vary from 64 to 2048 when the transmission bandwidth varies from 20MHz to 100MHz. These elements are adjusted according to the type of channel to be measured. The data carried by the subcarriers is a pseudo random QPSK sequence optimized so as to reduce the peak amplitude power ratio (PAPR) which is a known issue with OFDM.
Let us now explain how the system works. The emitter transmits continuously OFDM packets (with variable size and inter-packet interval). At the receiver side, the packets are received in their complex form and recorded in a file for later treatment. As for a traditional digital transmission system, classical packet mode OFDM synchronization algorithms have to be applied [8]. After this last step, the data is ready for extraction of the channel parameters. For each OFDM packet, two main pieces of information are available, namely the channel transfer function H(f,t) (after an FFT operation) and the channel impulse response h(τ,t) (CIR, after an IFFT operation). Hence, the channel can be tracked over time by monitoring the evolution of this information over the transmitted packets. Of course, for these treatments to be valid, a full characterization phase of the sounder RF chain has to be carried out. We are now ready to present how we have validated this channel sounding scheme in the next section.

## III. SYSTEM VALIDATION

In order to validate the OFDM channel sounder we have characterized an indoor environment using two other tools which can be considered as references since they have been validated by previous research works. The first tool is a 3D ray tracing software called RaPSor and developed in our lab. It is based on a 3D ray tracing associated to the Geometrical Optics laws (GO) and the Uniform theory of Diffraction (UTD) [9]. The second tool is a vector network analyzer (VNA) which is a classical measurement equipment used for indoor channel sounding.

The test environment is the video conference room of our lab and is represented in Fig. 4 with the position of the transmitter and the receiver. The goal is to capture the CIR of the channel for the position of the transmitter and the receiver shown in the figure. The results for the three systems are presented in Fig. 5 for 2.3GHz and 5.8GHz. As can be seen, the VNA and the OFDM channel sounder capture the same multipath components (MPCs) with an amplitude which is very close. The results are also in good agreement with the RapSor simulator. An interesting thing to notice is that RapSor does not find MPCs after 100ns as opposed to the measurement devices. This fact underlines the limit of this kind of deterministic simulator: it is difficult to model accurately all the elements of a real environment and their electromagnetic properties.

## IV. Case Studies

### A. FoF context. Measurement campaign at Airbus

In the context of the Factory of the Future (FoF) there is an increasing demand of real time data collection from different actors being either humans or machines. A lot of this data comes from wireless devices which raises the problem of the link availability depending on the wireless propagation channel. In the case of an industrial environment, in addition to multipath propagation there is also impulsive noise (mainly caused by rotating machines) which can severely impact the wireless communication [10]. In particular, Airbus is working constantly on improving the reliability of their industrial processes. Wireless smart tools used by operators assembling the planes help them to realize efficiently an operation (e.g. virtual reality assistance for a complex assembly operation) but also allows to collect information about the operation for quality control and tracking. Often these operations have to be performed in quite confined areas of the plane such as in a central wing box.

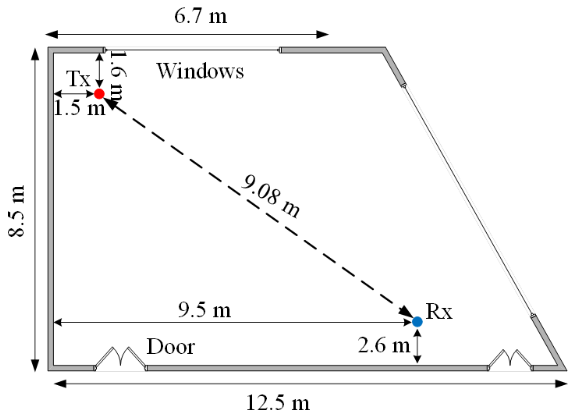


Fig. 4. Visio conference room SP2MI building 3rd floor.

We conducted a channel measurement campaign in a large factory hall at Airbus in Toulouse where test planes are disassembled for structure analysis. Airbus wanted us to measure the radio channel for several typical plane assembly situations where the wireless communication could fail. One of these situations is the assembly of a part inside a centre wing box with a smart tool. Thanks to the small size of our channel sounder we have been able to measure the channel between an external receiver and a transmitter inside the wing box. The measurement configuration is represented in Fig.6.

We expected no communication since the metallic wing box showed a Faraday cage configuration. But thanks to the small openings on the side we discovered a quite rich multipath environment. Fig. 7 and 8 show respectively the channel transfer function and the CIR during a 2.3GHz transmission of 100 OFDM packets using a transmission bandwidth of 20MHz (50ns path delay resolution).

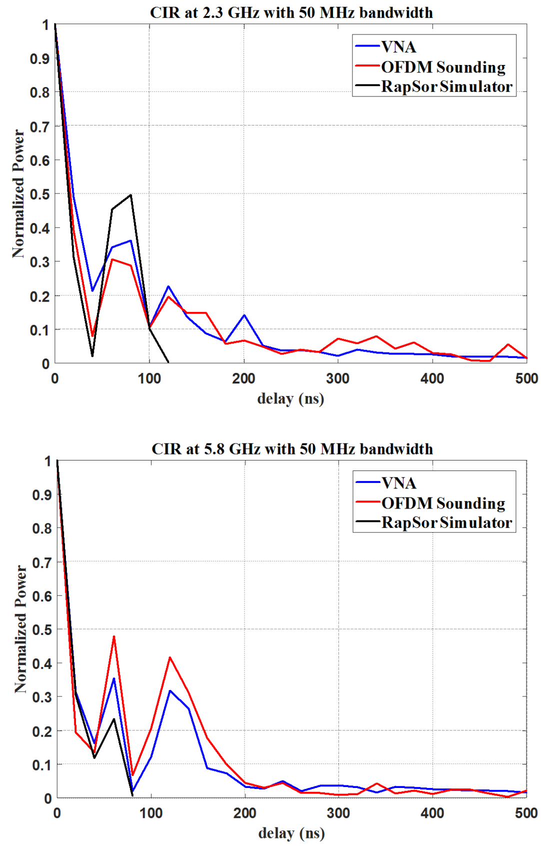


Fig. 5. CIR of the test environment for 2.3GHz and 5.8GHz

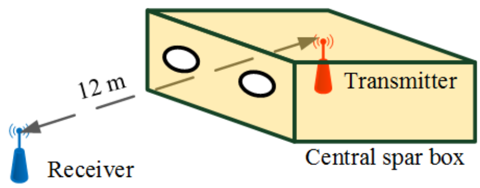


Fig. 6. Plane central wing box channel measurement setting

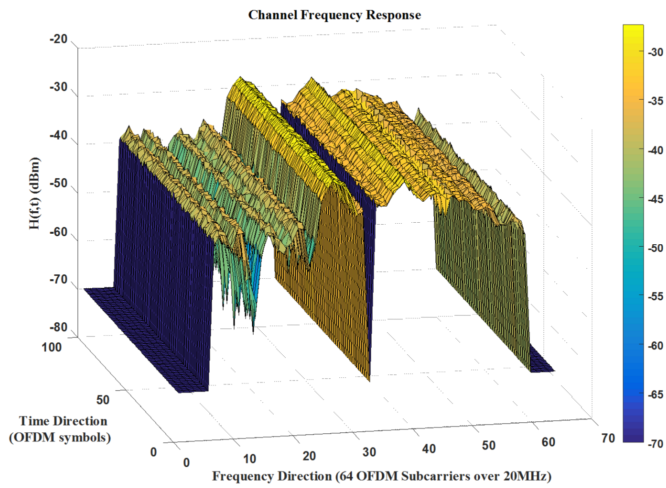


Fig. 7. Central wing box communication frequency response at 2.3GHz

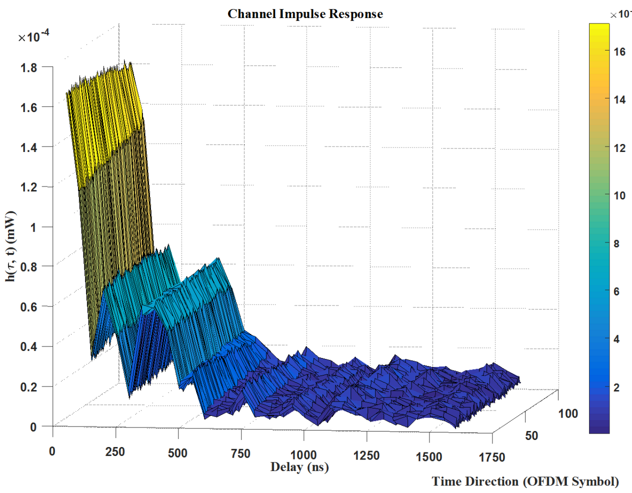


Fig. 8. Central wing box communication CIR at 2.3GHz

### B. *An embedded sounder application: determining the MPC components on a high speed telemetry test field*

This measurement campaign has been performed at the ISL experiment field in Baldersheim, France in order to identify the main MPCs for the characterization of a supersonic speed-ground projectile channel [11]. The transmitter was embedded on the drone of Fig. 3 which followed the route of the projectile at the same altitude. Fig. 9 shows the CIR obtained at a position of interest (near the gun). As can be noticed, there are more fluctuations observed than for the static situation described in the previous section.

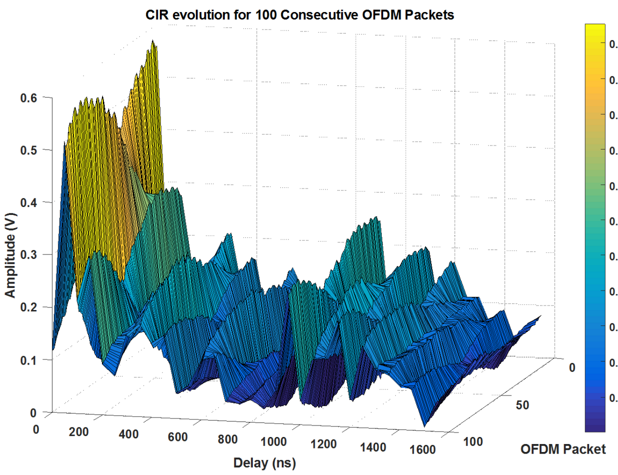


Fig. 9. Drone communication CIR at the gun position (2.3GHz)

## V. CONCLUSION

We have presented an OFDM based channel sounding technique which can be implemented thanks to relatively low cost SDR equipment. It can also be integrated on a small low power embedded system using the SoC-FPGA technology [5] which allows measurements in confined environments (see section IV). The information gathered from the channel consists in the frequency response and the CIR. Hence, the technique allows for the identification of the main MPCs of a wireless environment as would a VNA do. The evolution of the MPCs during time can also be monitored by analyzing successive OFDM packets. Thus, speed induced effects can be evaluated (i.e. the Doppler spread). Moreover, by using a path tracking algorithm, the amplitude and phase of each MPC can be monitored over time and probability density functions be obtained from these data. The procedure will result in a realistic statistical channel model which can then be used in a digital communication system simulator. This is the primary target of our OFDM channel sounder.

However, some limitations exist. The first one is, when comparing to a VNA, that the CIR always starts at 0, i.e. due to the synchronization system used it is not possible to know the exact delay of the first path. The 0 is the time of the digital receiver, all the path delays being relative to this reference. The other drawback is the need of a relatively high speed data interface and disk to save the data in real time. This means that the current maximum sounding rate is 100MSps. Moreover, the RF chain has to be well characterized and OFDM synchronization algorithms have to be very accurate.

These last two drawbacks have been well taken into account in our system. We are currently working on pushing some algorithms on the SDR FPGA in order to reduce the data rate to the PC. By doing so we will be able to reach a 200MSps which is the maximal rate achievable with Ettus Research X310 equipment.

## ACKNOWLEDGMENT

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## REFERENCES

[1] http://www.channelsounder.de/ruskchannelsounder.html

[2] J. D. Parsons et al., "Sounding techniques for wideband mobile radio channels: a review", IEE Proceedings I - Communications, Speech and Vision, Vol. 138 , Issue 5, pp. 437-446, Oct. 1991.

[3] D. C. Cox, "Delay Doppler characteristics of multipath propagation at 910 MHz in a suburban mobile radio environment," in IEEE Transactions on Antennas and Propagation, vol. 20, No. 5, pp. 625-635, Sep. 1995.

[4] https://www.ettus.com/product/details/X310-KIT

[5] https://www.altera.com/products/soc/overview.html

[6] http://www.terasic.com.tw

[7] http://www.analog.com

[8] M.-J. Canet et al. , "FPGA implementation of an OFDM-based WLAN receiver", Microprocessors and Microsystems, Elsevier, Volume 36, Issue 3, May 2012.

[9] F. Escarieu et al., "Outdoor and indoor channel characterization by a 3D simulation software," in Proceedings of the 12th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'01), pp. B105–B111, Boston, Mass, USA, Oct. 2001.

[10] M. G. Sanchez, I. Cuinas, A. V. Alejos, "Interference and impairments in radio communication systems due to industrial shot noise", Industrial Electronics, 2007. ISIE 2007. IEEE International Symposium on, pp.1849-1854, 2007.

[11] H. Boeglen, L. Barbero, A. Traore, D. Schmoltzi, R Vauzelle, "Analysis of the Doppler behavior on a supersonic speed ground-projectile channel", EUCAP'16 conference, Davos, Switzerland, Apr. 2016.