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EXTENSION OF SIMO WIDEBAND CHANNEL SOUNDER FOR UWB PROPAGATION EXPERIMENT

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Abstract—Good knowledge of transmission channel properties is necessary to study the performances of future UWB systems. Thus, efficient equipment is required to characterize and model the UWB propagation channel. This paper proposes a basic idea to convert a SIMO wideband channel sounder into an UWB channel sounder. These minor changes were applied to the France Telecom R&D channel sounder. The modified equipment enables real time measurement in the 3.1 – 10.6 GHz frequency band with more than 1 GHz bandwidth.

Index Terms— Channel sounding, radio propagation, ultra-wide bandwidth.

1. INTRODUCTION

UWB techniques have been known in radar application for several decades. Nevertheless, the use of this technology in radio communication is relatively new and very promising. The FCC frequency band is defined between 3.1 and 10.6 GHz. To exploit all the benefits of the UWB concept, it seems interesting to use the whole allocated frequency band. However, it is difficult to generate such narrow pulses. Moreover, the temporal diversity seems to decrease above 1 GHz bandwidth [1]. This probably explains the emergence of multi-band solutions with about 1 GHz bandwidth.

Future UWB telecommunication systems will be used in mobile indoor configurations. The effect of people or moving obstacles on the channel impulse response will be very important. Thus, it is necessary to characterize the short-term variability of the propagation channel in UWB radio links.

This paper aims to present simple modifications which enable to extend a SIMO wideband channel sounder to an efficient UWB channel sounder. Section 2 will review usual methods to measure the UWB propagation channel. Then, the basic structure of our SIMO channel sounder will be introduced (section 3). Next section will present hardware modification and post processing. We will conclude by presenting some measurement results to demonstrate the first capabilities of this new equipment (section 5).

2. UWB SOUNDING TECHNIQUES

Currently, most of UWB propagation experiments use a Vector Network Analyser ([1], [2], [3], [4], [5]). The frequency sounding technique is widely known, due to its ease and advantages of implementation. Firstly, there is no limit on the frequency bandwidth. The only limits are usually imposed by antenna characteristics. Secondly, the dynamic range of measurement is good enough if Low Noise Amplifiers are used. For instance, very precise analysis can be performed using a virtual planar array. Nevertheless, the duration of the frequency sampling and the data transfer is quite long, lasting several seconds for each measurement point. During the acquisition time, the propagation channel needs to be constant. As a consequence, this approach is limited to the characterization of static environments. The effect of moving people cannot be investigated with this method.

For dynamic channel measurements, the first solution is to use a UWB chip in the transmitter equipment to actually emit UWB pulses, with a spectral bandwidth above 1.5 GHz. The channel impulse response is then estimated by sampling the received signal with a Digital Sampling Oscilloscope ([6], [7]). This method is quite simple to implement. However, the transmitted waveform is imposed and the dynamic range of measurement is limited (high level of noise and low level of power).

The second solution to sound dynamic channels consists in using a wideband channel sounder and measuring several adjacent partial bands. This principle was investigated and successfully implemented in [8]. The main problems are the fast generation of various oscillators and the synchronization of the signals. The mentioned equipment was able to measure a propagation channel every 300 μ s with 600 MHz bandwidth.

In indoor configuration, the speed of moving terminals is about 2 m/s. Considering the worst case, a maximum frequency of 10.6 GHz and a mobile terminal, the maximum Doppler shift is $v / \lambda = 70$ Hz. This maximum Doppler shift increases to $2.v / \lambda = 140$ Hz if one considers mobile scatterers, taking into account the paths with one reflection as significant paths. Thus, to

characterize time variant UWB propagation channels, the equipment has to sample the channel every 3.5 ms.

Considering the UWB multi-band concept with a bandwidth between 500 and 700 MHz, our brief overview shows that there is only a few equipments really suited for such characterization. Moreover, there is no equipment available to probe greater bandwidths in order to study the limit of the multi-band channel size.

3. PRINCIPLE OF SIMO CHANNEL SOUNDER

The basic idea to perform dynamic UWB channel measurements is to measure several adjacent partial bands using a wideband channel sounder. The main problems to overcome are the fast switching of the partial bands with full synchronization with the transmitted sequence; the calibration of each sub-band (with respect to phase, amplitude and delay); the high dynamic range; and the real time constraint.

This problem is quite similar to SIMO wideband characterization. Thus, we studied the SIMO sounding structure to reuse most of the elements for UWB characterization. For a better understanding, this section reviews the general structure of our SIMO wideband channel sounder. More details can be found in [9].

The receiver (Fig. 1) can measure up to 10 inputs. To repeat measurements as fast as possible, antennas are switched every other sequence. The first sequence is used for data sampling and the following time slot for antenna switching. This principle can be applied because the transmitted signal is periodic. Practically, a fast switch is used to select one of the incoming signals. The signal is then amplified using a wideband LNA (3-18 GHz) and pass-band filtered. The filter characteristics depend on the analysed frequency band. The output frequency of the first down-converter is 1.5 GHz. The following 60 dB attenuators are used to compensate for the power variations of the received signal (Automatic Gain Control). The AGC is performed before the measurement of the multiple inputs. Thus, the AGC duration limits the maximum measurement repetition rate. In a usual configuration with 10 inputs, the maximum rate is about 830 Hz. The second down-converter is centered at 250 MHz. The output signal is then sampled by a 1 Gsample/s digitaliser.

On the transmitter side, an arbitrary waveform generator (1 Gsample/s) produces a real periodic sequence which occupies a maximal bandwidth of 250 MHz centered around an Intermediate Frequency of 250 MHz. This signal is then up-converted around the carrier frequency. It can be noticed that transmitter and receiver parts use the same Intermediate Frequency.

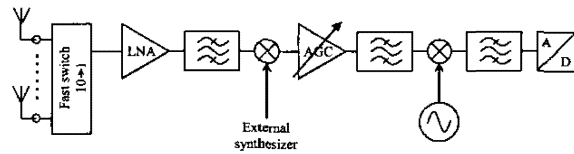


Fig. 1. Block diagram of the receiver.

Thus, the frequency of the local oscillator is the same in both the transmitter and receiver. All synthesizers are synchronized on a 10 MHz reference rubidium.

The calibration is very important in SIMO configuration. Each channel needs to be calibrated in amplitude, phase and delay. The principle is to connect the transmitted signal directly to the receiver. A calibrated RF coupler is used to split the transmitted signal through the different inputs. This wideband reference measurement takes into account all the characteristics of the inputs: absolute gain and delay, phase, gain variation in the sounding band... This reference and the characteristics of the coupler are used during the channel impulse estimation (Wiener inversion). This process naturally calibrates each input.

4. EXTENSION TO UWB

4.1. Principle

In order to convert our SIMO channel sounder into an UWB channel sounder, we exploited the duality between multiple input measurements and multi-band measurements. The basic idea of this concept is to use the multiple input switching module for the synchronous switching of the carrier frequencies of all partial bands to be measured.

The practical realization of this concept is presented in Fig. 2. As we can see, the input connector is now directly connected to the LNA, while the Fast Switching Module sequentially feeds the mixer of the first down-converter stage with one of the 10 oscillator signals (F_1 to F_{10}) in turn. These signals are generated by external synthesizers and tuned so that the receiver actually sweeps the desired partial bands. This configuration allows for single input, multiple band measurements with up to 10 partial bands of 250 MHz each, hence UWB measurements are theoretically possible with a bandwidth up to 2.5 GHz.

On account of its development concept, this extended channel sounder naturally fulfils most of the required criteria for real-time UWB channel measurement. Regarding the calibration of each partial band in terms of phase, amplitude and delay, the same

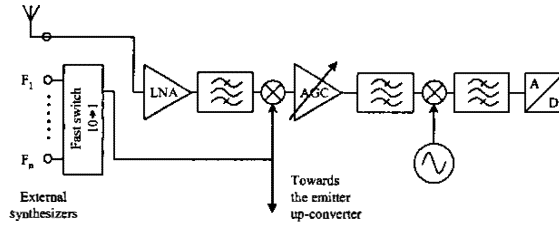


Fig. 2. Block diagram of the modified receiver for the extension to UWB.

procedure as in the SIMO configuration remains valid, except that there is no more use of a coupler.

Concerning the fast switching of the partial bands, no software modification is needed. First, the frequency switch is still synchronized with the transmitted sequence period. Second, the sweep time through all partial bands may be reduced down to 1.2 ms, allowing the measurement of the time variations of the channel with a Doppler shift up to 416 Hz. Third, acquisition is performed every other sequence, leaving one sequence for frequency switching. Undoubtedly, the frequency switching case is more critical than the input switching case, as the emitted signal is no longer periodic. Thus, it is necessary to wait the end of the transient state before sampling a new sequence. However, given the length of the emitted sequence (2.048 μ s), the maximum path lengths in indoor configurations (about 150 m) and the duration of the actual frequency switch ($t_{\text{switch}} \approx 100$ ns), the condition is met at the start of the sampled sequence. This configuration remains valid as long as the following inequality is fulfilled:

$$t_{\text{switch}} + t_{\text{LOS}} + \tau_{\text{max}} < t_{\text{seq}} \quad (1)$$

where t_{switch} is the switch duration, t_{LOS} is the absolute delay of the LOS path, τ_{max} is the maximum recordable delay with respect to the LOS arrival time and t_{seq} is the duration of the sequence. A graphical representation of this concept is given in Fig. 3.

4.2. UWB specific issues

In addition to the main modification regarding the use of the Fast Switching module, further changes have been performed on our SIMO channel sounder in order to address some UWB specific issues.

a) *Filtering:* in the SIMO channel sounder, the filter preceding the first down-converter stage in the receiver (Fig. 1) was only a few hundreds of MHz wide to reject undesirable signals and reduce the noise level. The same type of filtering is performed in the emitter. In the UWB configuration, however, the sounded frequency band

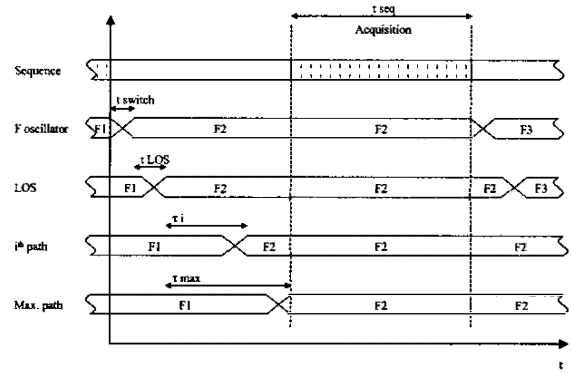


Fig. 3. Chronogram of the switching and acquisition phases at the receiver.

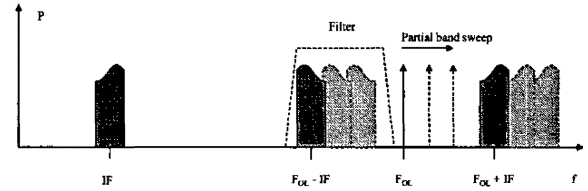


Fig. 4. Sub-band sweep and filtering.

needs to be filtered by one single pass-band filter, in order to avoid unnecessary filter switching. In the current version of our SIMO channel sounder, the Intermediate Frequency of this stage is 1.5 GHz. The maximum filter width is hence limited to 1.5 GHz, for the unwanted Local Oscillator signal to stay outside the filter limits during the whole partial band sweep. This situation is depicted in Fig. 4.

In order to increase the size of the measurable bandwidth, another configuration is available in the SIMO channel sounder, with an IF at 5.5 GHz. Using this configuration, it would be possible to enlarge the filter bandwidth to the limit of 2.5 GHz imposed by the number of available partial bands. The only condition in this mode of measurement would be to avoid the IF frequency of 5.5 GHz in the scanned band.

In its current state, our UWB channel sounder has been equipped with filter bandwidths up to 1.2 GHz, which is thus the limit of the currently measurable bandwidth.

b) *Synchronisation:* Unlike the SIMO channel sounding case, UWB measurements using the sweeping method necessitate a constant modification of the emitted signal central frequency. For this reason, the frequency switch performed at the receiver and at the emitter need to be perfectly synchronised. To solve this problem, we chose to use the same Local Oscillator signal to feed both the receiver down-converter and the

emitter up-converter stages. This was possible since the receiver and the emitter use the same Intermediate Frequency. One drawback of this solution is that the emitter and the receiver parts need to be cable connected. However, in most indoor configurations, this connection is realizable using a cable of acceptable length. As an advantage, this solution allows one to use only one set of external synthesizers, which considerably reduces the global cost of the equipment.

c) Partial bands fine calibration: as presented earlier, the back-to-back measurement procedure inherited from the SIMO channel sounder permits a first calibration of each partial band. This procedure naturally adjusts the relative delay experienced for each partial band. One should note, however, that 10 external synthesizers are used in the UWB configuration. Despite their common 10 MHz reference, each of these devices undergoes an independent phase drift. To compensate for this unavoidable drift, a partial band fine calibration is performed after the measurement by post-processing. For this purpose, a given frequency overlap is required between two adjacent partial bands, over which the amplitude and phase of the recorded spectrums is compared and adjusted using a best fit criterion. In the current configuration, the best results are obtained using partial band overlaps of about 40 MHz, resulting in a reduction of the theoretical maximum measurable bandwidth from 2.5 GHz to 2.14 GHz.

5. EXPERIMENTAL VALIDATION

The modifications presented above have been applied to our SIMO channel sounder for its extension to real-time UWB measurements. The emitter up-converter and receiver down-converter stages have been equipped with filters with bandwidths of about 1 GHz. To sweep the desired frequency band, 5 external synthesizers have been connected to the Fast Switching module and tuned to the central frequencies of 5 partial bands.

In terms of sounding performance, our test results showed an Impulse Response dynamic of 40 dB. In this configuration with 5 partial bands, the minimum measurement repetition time is about 1 ms and the actual measurement duration is 20.5 μ s. With its 256 MB memory, the acquisition card is able to sound the time variant UWB channel for a duration of 80 s in standard conditions (bandwidth of 1 GHz and observable Doppler shift of 150 Hz).

For the first experimental results, the UWB channel sounder was parameterized to sound the 5 GHz - 6 GHz frequency band. Measurements were performed in a

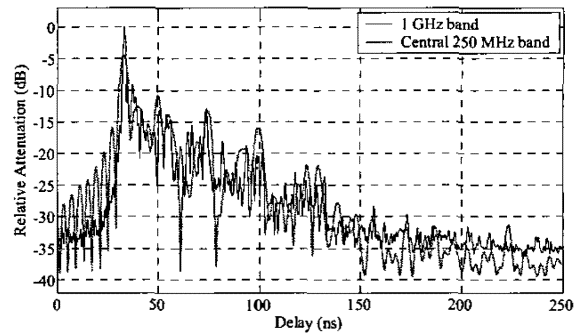


Fig. 5. Power Delay Profiles in a static environment.

large room representative of the indoor office environment, using an omni-directional antenna.

Fig. 5 shows the performance of the UWB sounder in a static environment, in the LOS configuration. Two Power Delay Profiles are represented, for the global 1 GHz band (black line) and the central 250 MHz band (grey line). The Impulse Responses have been averaged over 100 measurements for the purpose of noise reduction. The benefits of UWB in terms of resolution of the multipath components are clearly visible. In the 1 GHz band case, several multipath components are observable, while a few only are resolvable in the 250 MHz partial band case. The side lobes on the left hand side of the second curve are due to the rectangular window used in this graph for a finer resolution.

Results obtained in a dynamic situation are represented in Fig. 6 and 7. In this experiment, we used a mobile receiving antenna held by a moving person. Along the trajectory, both LOS and NLOS situations were encountered.

Fig. 6 presents a time-variant Power Delay Profile, showing a 12.5 s record of the signal obtained at the moving receiving antenna. For ease of interpretation, the excess delay has been converted in excess path in meters. In the first part of the trajectory (between $t = 0$ s and $t = 7$ s), the person is moving towards the emitter antenna, reducing its relative distance from 6 m to 2 m. Hence, one can observe a main path with increasing power (a). In the second part of the trajectory, (between $t = 7$ s and $t = 11$ s), the person is moving away from the emitter antenna, partially obstructing the line of sight. This explains the shadowing experienced by the shortest path (b). In this part of the curve, three other main paths are observable, one with increasing length (c) and two with decreasing lengths (d, e). These two last paths might correspond to echoes transmitted via a reflection on a wall opposite to the emitter location.

In order to visualize the Doppler shift experienced

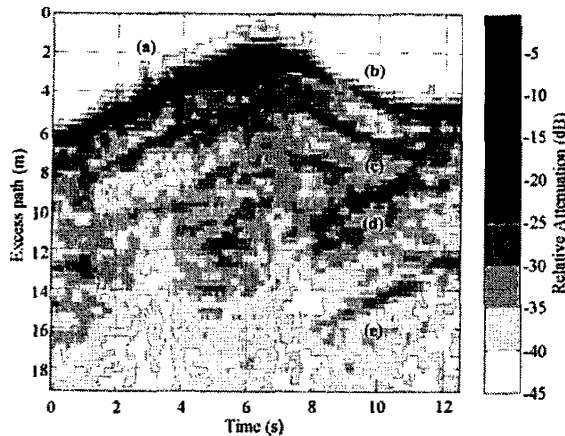


Fig. 6. Time variant Power Delay Profile in a dynamic indoor environment.

during the experiment, we computed the Scattering Functions corresponding to samples of 128 consecutive Impulse Responses. Fig. 7 represents an average of the Scattering Functions obtained from Impulse Responses recorded between $t = 8$ s and $t = 11$ s.

One can observe that the maximum recorded Doppler shift is about 20 Hz in this experiment, which corresponds to a motion speed of 0.5 m/s for maximum frequency of 6 GHz. This corresponds to the experimental conditions. This limited Doppler shift demonstrates the ability of the UWB channel sounder to perform real time measurements of dynamic channels, as the sampling frequency in the time domain is high enough to avoid aliasing effects. In the current configuration, Doppler shifts up to 416 Hz could be recorded.

6. CONCLUSION

In this paper, we demonstrated the feasibility of developing an UWB channel sounder by applying minor changes to a SIMO wideband channel sounder. Using this technique, most of the channel sounders capable of multiple antennas measurements could be extended to UWB channel sounding. Experimental results were presented, showing the ability of our modified equipment to perform real time UWB measurements with 1 GHz bandwidth and a high dynamic of the Impulse Response. Further modifications, including the increase of the number of partial bands and the use of another Intermediate Frequency, will permit to extend the measurable bandwidth to more than 2 GHz with a measurement repetition time as low as 1.2 ms. Another possible extension of this concept would be to make use of the capabilities of MIMO channel sounders to realize

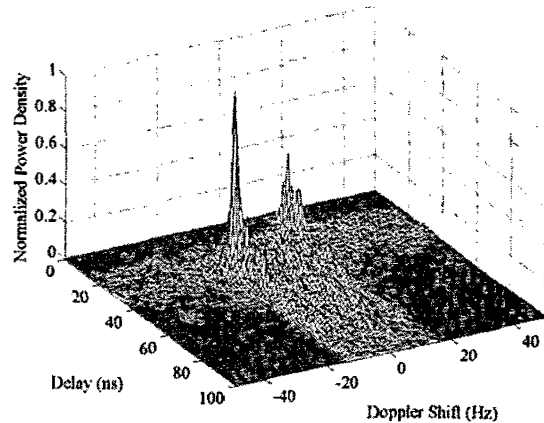


Fig. 7. Mean Scattering Function experienced between $t = 8$ s and $t = 11$ s.

dynamic UWB measurements on an array of multiple antennas. The UWB channel sounder currently developed at France Telecom R&D will be used in future measurement campaigns, in order to precisely characterize the temporal fluctuations of the UWB Impulse Response in an indoor environment.

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