Ultra-Wideband Real-Time Channel Sounder and Directional Channel Parameter Estimation

R. Zetik, R. Thomä, J. Sachs

Electronic Measurement Research Lab, Technische Universität Ilmenau, PF 100565, D-98684 Ilmenau, Germany

Abstract: An Ultra-Wideband (UWB) real-time channel sounder architecture is described which allows the measurement of the time-variant radio propagation channel in the extreme wide band ranging from nearly zero to 5 GHz. Synchronous multi-channel operation is supported by excellent timing stability and low power consumption of miniature size LTCC modules comprising custom integrated SiGe HBT circuits. This is a prerequisite to build a Multiple-Input-Multiple-Output (MIMO) sounder. Measurement examples using the experimental UWB sounder system are presented and the application for high resolution directional channel parameter estimation is shown.

ITRODUCTION

Recently, UWB wireless transmission has been discussed as an alternative technology for application in short range indoor and personal area networks and for fixed wireless access. UWB systems may be applied in the base-band by using carrier-less modulation with very low power spectral density as a result of extreme data bandwidth spreading. This makes UWB a potential candidate for a cheap license free transmission system which may share the spectrum with other systems.

The proper design of UWB communication systems requires the knowledge of the deterministic and stochastic behavior of the transmission channel in canonical radio environments. This is described by the time-variant Channel Impulse Response Function (CIRF) which includes information about multi-path delay, Doppler spread, and the time-varying path weights. There has been a great deal of effort directed to investigating the behavior of the CIRF by theoretical modeling and measurements using channel sounders in a real environment. Although those existing real-time sounding systems are often called “broadband”, they do not meet the extreme requirements of bandwidth and base-band operation. The UWB-system described here currently works in a frequency band from almost DC to 5 GHz corresponding to a fractional bandwidth of nearly 150 %. In the near future, the upper cut-off frequency will be expanded to 10 GHz leading to 170% of fractional bandwidth.

The paper starts with a short description of the experimental UWB channel sounder. Measurement examples using the experimental UWB sounding system are presented. From the measured data high resolution estimation of the directional channel parameters is demonstrated.

EXPERIMENTAL CHANNEL SOUNDER SYSTEM

An experimental multichannel UWB sounding system covering the band from near DC to 5 GHz was tested using UWB circuits (shift-register, binary divider and Track-and-hold circuit (T&H)) which have been designed at Ilmenau University of Technology in cooperation with MEODAT company [5] for ground penetrating radar application. Fig. 1 presents sounder basic architecture. Controlled by a single tone clock, a digital shift register generates the MLBS signal and a binary divider (2^m) provides the receiver sampling

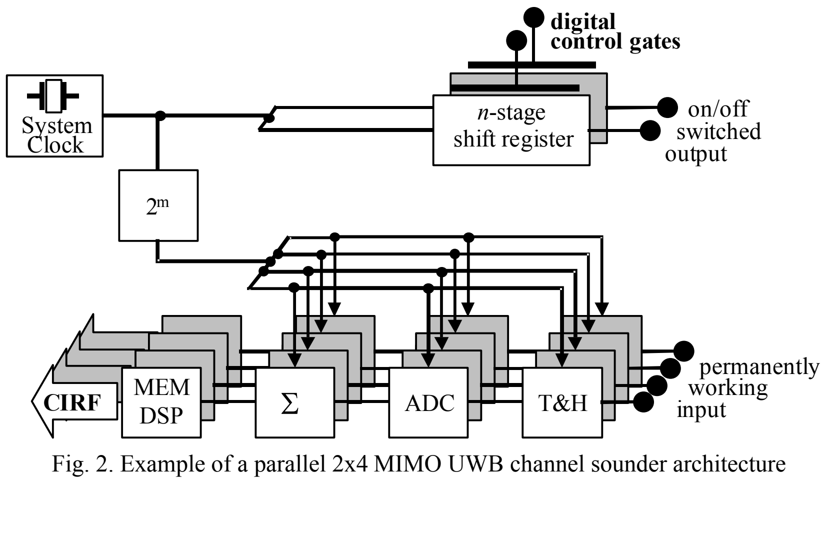

Fig. 2. Example of a parallel 2x4 MIMO UWB channel sounder architecture

clock. In case of experimental sounder there is direct connection between transmit and receive sounder unit. However, in the future there should be only wireless synchronization betweens these two sounder parts. The measurement data are undersampled by a T&H, transformed into the digital domain (ADC), optionally synchronously averaged (p) and finally stored (MEM) for off-line processing or on-line processing (DSP). The CIRF results from an impulse compression which is performed by the FHT (Fast Hadamard-Transform). The FHT-algorithm is very close to the FFT-algorithm except that it is based on a pure summing of data samples which promises very fast operation for special hardware implementation.

The superior jitter and drift behavior is a result of the integrated implementation in 0.25µm SiGe-Technology featuring 55GHz transit frequency (fabricated at IHP Frankfurt/Oder). The extremely linear time axis (compared to traditional sequential sampling oscilloscopes) is the result of the synchronous digital controlled sampling. Besides of the custom designed SiGe chips, the RF modules use multi-layer LTCC (low temperature co-fired ceramics) circuit technology. The DSP module of the described experimental systems is based on standard off-shelf PCB products. The ADC is a 12-Bit-Video ADC and the sampling frequency was 17.68MHz (depends on the adjusted undersampling factor). For more details on the system and circuit design, the reader is pointed to [1], [2], [3]. A 9x9 MIMO system has been tested in the lab already.

DIRECTIONAL CHANNEL PARAMETER ESTIMATION

The goal of the channel sounding is to extract the structure of the channel from measured data taking into account not only various time shifts and signal forms of the received signal echoes but also theirs various directional characteristics as illustrated in the Fig.2. In [6], it was demonstrated how is it possible to extract the information about the directional characteristics from UWB measurements by means of delay-and-sum beamforming. The precision of the beamforming is dependent on the number of antenna elements in the receive antenna array. In [6], 49 element antenna array was used during the measurement resulting in the angular resolution of 15 degrees. However, the directional characteristics can be estimated with much higher precision using a different approach than beamforming. This will be demonstrated further within this chapter.

Another solution is to estimate directional channel information by using wide spread distributed transmitters to estimate the position of a mobile receiver. The same idea can be used for the estimation of time shifts, DoDs (DoAs) of multipath components arising from the dominant scatterers. In this case the distance from a reference point to the receiver (scatterer) is measured and the receiver (scatterer) position is calculated by basic geometric relations. The precision of the estimation depends on the range resolution and on the geometric position of the transmitters. Since UWB systems feature an excellent non-ambiguous range resolution (as illustrated in e.g. [8]) it is assumed that they will also allow high precision estimation of the channel directional characteristics. This will be demonstrated further by a measurement example.

MEASUREMENT EXAMPLE

This measurement example demonstrates how precisely it is possible to estimate the 2D position of a transmit antenna in the free space with LOS available (or in other words time shift and DoD of the direct wave).

Within this example, the transmit antenna was mounted on a 2D positioning unit allowing the precise positioning of objects in an area of 2 meters by 4 meters with 0.75 mm precision in two directions. The transmit antenna was moved along a predefined track with the maximum velocity (170mm/s) allowed by the positioning unit. Data was measured by the experimental UWB system with measurement rate adjusted to be approximately 11 scans per second and the whole measurement lasted only for about 90 seconds. A linear Vivaldi antenna array containing four antennas was used as the receive antenna and a biconical omni directional antenna was used as the transmit antenna. Each measured impulse response scan contains 511 samples spaced by 111ps. This means that the time delay estimation using only simple maximum value detection would provide resolution of about 3cm. However, the resolution was considerably increased by means of a high-resolution maximum likelihood (ML) estimator that was based on the ML estimator used for the wideband channel sounding in [9]. The estimation results are displayed in Fig. 3. The track along which the transmit antenna was moved is the connection of the points with the following coordinates [0;0], [0;2.5], [0.8;2.5], [0.8;1.5], [-0.9;1.5] and [-0.9;0]. The estimated positions are depicted as the dots. The standard deviation of the estimation error was approximately 1.5 cm in both directions of Cartesian co-ordinate system and the maximum error of azimuth estimation was approximately one degree.

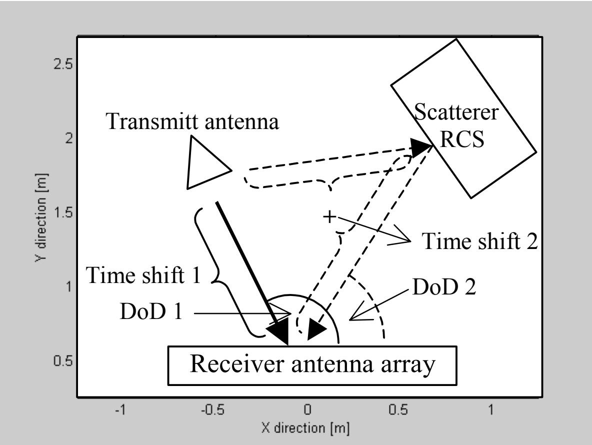

Fig. 2 Channel sounding

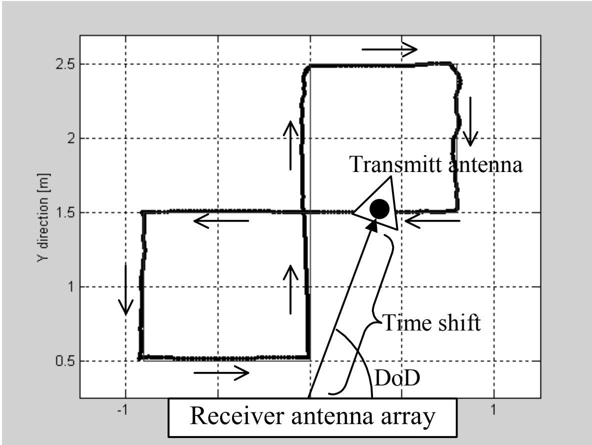

Fig. 3 2D position (time shift and DoD) estimation of the moving transmit antenna

CONCLUSIONS

The experimental version of a real-time UWB MIMO sounder featuring 5 GHz bandwidth was described. Its key advantages are (i) high measurement speed, (ii) excellent stability in time and low jitter, (iii) multi-channel capabilities and its flexibility.

The idea on how is it possible to accomplish high precision estimation of the directional channel information using wide spread distributed transmitters was shortly discussed.

The 2D measurement example of the direct wave time shift and DoD estimation was given in order to demonstrate the potential of the experimental channel sounder architecture for estimating and analyzing the directional structure of the UWB MIMO channel.

REFERENCES

[1] Sachs J., Peyerl P., Roßberg M., “A New UWB-Principle for Sensor-Array Application,” *IMTC/99*, May, 1999, Venice, Italy.

[2] Roßberg M., Sachs J., Rauschenbach P., Peyerl P., Pressel K., Winkler W., Knoll D., “11 GHz SiGe Circuits for Ultra Wideband Radar,” *IEEE Bipolar/BiCMOS Circuits and Technology Meeting*, September 2000, Minneapolis, USA.

[3] Sachs J., Roßberg M., Rauschenbach P. , Peyerl P., Friedrich J., “Integrated UWB Radar Circuit for Base Band Applications from DC to 5 GHz”, *GRS 2000* , October 2000, Berlin, Germany

[4] Evans D.J., Cloude S.R., “An Ultra-Wide-Band Antenna Array for Ground Penetrating Radar Detection,” *AP2000*, Davos, Switzerland.

[5] www.meodat.de

[6] Cramer R.J.M., Win M.Z., Scholtz R.A., “Evaluation of the Multipath Characteristics of the Impulse Radio Channels,” *IEEE1998International Antenna and Propagation Symposium*, June 1998, pp. 626-630.

[7] Thomä, R.S.; Hampicke, D.; Landmann, M.; Richter, A.; Sommerkorn, G., “MIMO Channel Sounding and Double-Directional Modelling,” *XXVIIth URSI General Assembly*, August 2002, Maastricht, NL.

[8] Zetik, R.; Thomä, R.; Sachs, J., “Ultra-Wideband Real-Time Channel Sounder Design and Application,” COST273 Temporary Document TD(03) 201, Prague, Czech Republic, September 2003.

[9] Richter, A.; Landmann, M.; Thomä, R.S., “A Gradient Based Method for Maximum Likelihood Channel Parameter Estimation from Multidimensional Channel Sounding Measurement,” XXVIIth URSI General Assembly, August 2002, Maastricht, NL.