UWB localization – active and passive approach

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Introduction

Ultra wideband (UWB) radar is of great interest for a vast number of applications such as surface penetrating radar, surveillance and emergency radar, medical instrumentation, non-destructive testing in civil engineering and the food industry, industrial sensors and microwave imaging and many others. The fractional bandwidth of the sounding waves for such types of applications should be as close as possible to 200 % resulting in a high spatial resolution and good penetration in materials.

Since UWB radars have excellent spatial resolution it is supposed that they can be advantageously applied in the field of localization and navigation. There are a number of applications that would take advantage from precise indoor positioning and navigation such as automatic storage, tracking of various targets (e.g. at airports), or people in dangerous environments (policemen, firemen) and so on

The UWB-system introduced here works currently in a frequency band from almost DC to 5 GHz corresponding to a fractional bandwidth of nearly 200 %. In the near future, the upper cut-off frequency will be expanded to 10 GHz.

The paper starts with a discussion of the basic requirements of UWB measurement electronic. Then, a new custom integrated UWB localizer architecture using analog and digital SiGe-circuits is introduced. Measurement examples using the experimental UWB localizing system are presented. From the measured data high-resolution estimation of a target position is demonstrated.

Proposed approach

Apart from the extreme bandwidth, the basic requirements posed on the electronics of UWB localizer are:

- a high data recording rate to match the time variance the channel under test (CUT),
- multi-channel arrangement capability in order to provide data for 2D or 3D target localization,
- a high degree of hardware configuration flexibility to adapt the system performance to the actual requirements of the individual user.

The key to a powerful UWB-localizer is the use of an appropriate stimulation signal because the whole device hardware and signal processing depends upon it. With regards to this point, the most important aspects may be summarized in the following:

- The stimulus must be an UWB signal which allows real time operation. Sequentially stepped narrow band signals are not suitable because they prevent real time operation due to the dead time during the system/CUT settling.
- The stimulus must be generated in a stable manner by simple means up to several GHz bandwidth.
- The stimulus must be periodic in order to apply cost effective sub-sampling methods for signal recording and to avoid a spectral bias error. It is allowed to work with a certain degree of sub-sampling without loss of data because of the limited time variation of the channel.
- The stimulus must have a low crest factor. Low crest factor signals distribute their energy uniformly over the time. This maximizes signals energy even at low peak voltages. However, impulse compression by correlation is required for impulse response (IR) estimation. This also maximizes the SNR of channel path weights by a correlation gain.

Signals that meet these requirements are pseudo-random-binary-sequences (e.g. MLBS). MLBS can easily be generated up to tenths of GHz of bandwidth by a digital shift register which is clocked by stable single tone RF-oscillator. Besides of the advantage of having a reasonable correlation gain, these signals are characterized by small binary voltage amplitudes that allow extremely fast digital switching in integrated circuit technology to meet the demanding requirements on bandwidth and low jitter. Fig. 1 presents the basic architecture of the baseband MLBS UWB localizer.

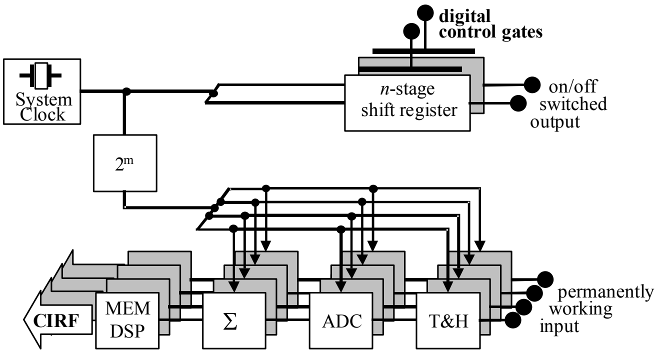

Fig. 1 Block diagram of the UWB RF interface

Results

Experimental System

An experimental multi-channel UWB system covering the band from near DC to 5 GHz was developed using UWB circuits (shift-register, binary divider and T&H) that have been designed at Ilmenau University of Technology in cooperation with MEODAT company. The superior jitter and drift behavior is a result of the integrated implementation in very fast SiGe-Technology (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). Examples of already developed UWB electronic capable of real-time measurements with the measurement rate up to 40 000 IRs per second are illustrated in Fig. 2 and 3.

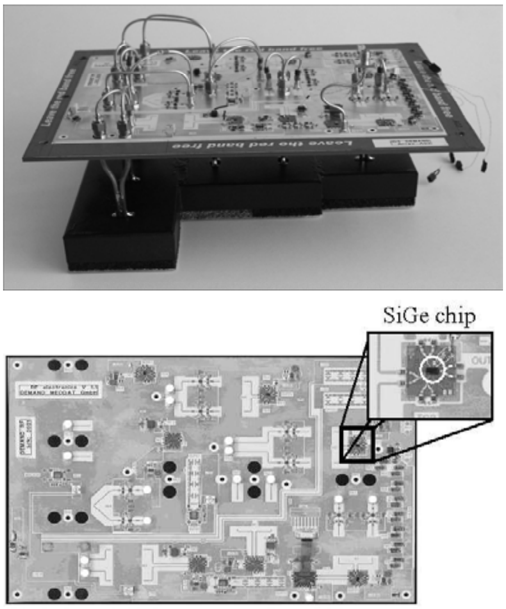

Fig. 2 UWB electronic with 4Rx/3Tx channels

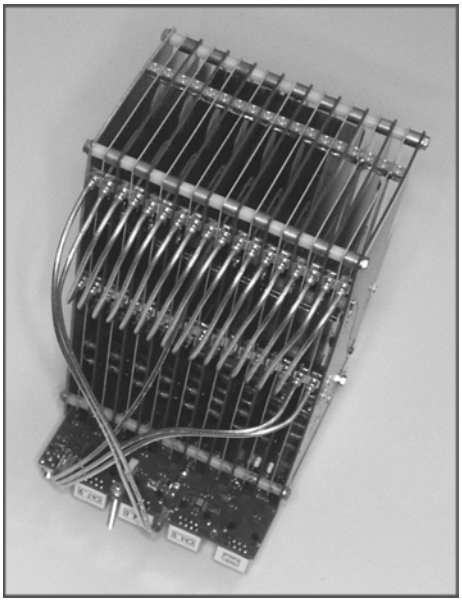

Fig. 3 UWB electronic with 9Tx/9Rx channels

Positioning

In case of UWB localization and distributed antennas, paradigm shift from phase difference to time-delay-of-arrival (TDOA) estimation seems suitable to estimate the target position. There are two different positioning approaches: active and passive. The main difference between these two approaches is that the active approach presumes that objects to be positioned cooperate with the positioning device and carry one part of its hardware usually a receiver. However, there are applications in which a transmitter is attached to the object.

Since the range resolution is mandatory for the precision of the position estimation the following measurement example was performed in order to demonstrate the excellent range resolution of the experimental UWB system. Here, the transmitter and receiver were connected through a mechanical delay line allowing 0.2mm precise distance adjustments. 38 measurements were recorded with different delays adjusted by the delay line (20 measurements with 200 μm delay step, 9 measurements with 2mm delay step and 9 measurements with 2cm delay step). The pulse position was estimated by means of a high-resolution maximum likelihood (ML) estimator that was based on the ML estimator used for the wideband channel sounding. The resulting error is presented in Fig. 4. For small delay steps (first 20 scans) the error is below 200μm. The estimation error increases as the delay variations become larger. This was caused by cross-talk between transmitter and receiver. This effect can be considerably reduced by the proper calibration.

The next measurement example demonstrates how precisely is it possible to estimate the 2D position of a transmit antenna in the free space with LOS (active approach). The transmit antenna was mounted on a 2D positioning unit allowing the precise positioning of objects with 0.75 mm precision in two directions. The transmit antenna was moved along a predefined track. Data were 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. The estimation results are displayed in Fig. 5. 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 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.

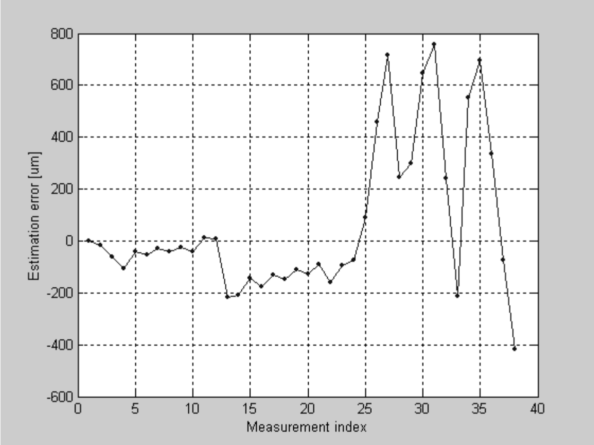

Fig. 4 Error of the distance estimation

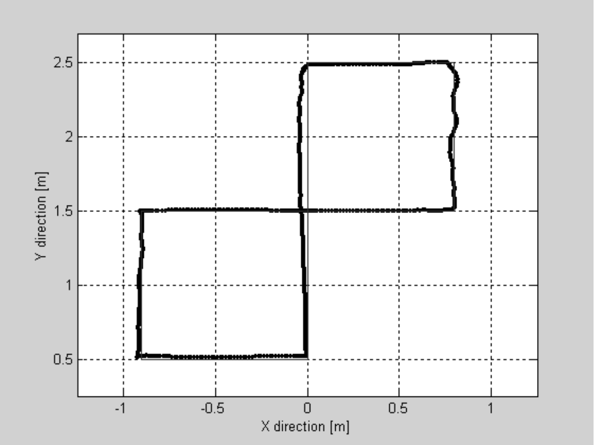

Fig. 5 2D position estimation – active approach

An example of 3D position estimation is illustrated in Fig. 6 and Fig 7. Here, the transmit antenna was moved by the hand in the air writing the year “2003”. The estimated result can be identified from detailed view displayed in Fig. 7.

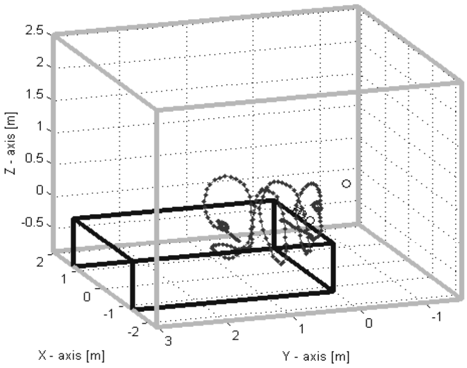

Fig. 6 3D position estimation

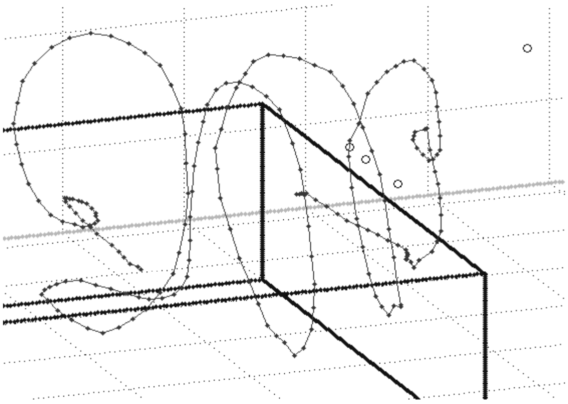

Fig. 7 Detailed view

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