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A familly of M-Sequence based UWB sensors

Introduction

The interest in using of ultra wideband (UWB) sensors with attention to scientific, technological and economical background is rapidly increasing. The M-sequence based ultra-wideband (UWB) sensors are a new technology capable of use in the various areas of the civil, industrial and last but not least military scene. Among the possible applications, M-Sequence based UWB technology may be used for imaging, ground penetrating radars, localization, non destructive testing, and radio channel investigation in communication systems engineering. This article describes the UWB sensor family based on M-Sequence stimulus signal.

Meanwhile, some extended M-Sequence concepts have been introduced and are under investigation. The article gives an overview about the realized improvements and possible extensions.

Design Challenges

Designing ultra-wideband sensor systems presents several levels of challenges. In the first place to chose a suitable stimulus signal. The classical and as yet mostly used UWB-approaches are based on short pulses and swept sine waves. As an alternative to these techniques we developed the M-Sequence based system. The reasons for that was already introduced [1] and will not considered here for further details. In the main, the big advantage of such a system is that the signal energy is homogenously distributed over the time avoiding high signal peaks. This allows a monolithic circuit integration of the critical RF-parts. Therefore, the second challenging level is the having of fast and low noise transistors. Traditionally, wideband circuits relied on transistors based on III-V technologies. For silicon-based technology, however, both CMOS and bipolar devices have made great progress in high-frequency performance. The state-of-the art n-MOSFETs and SiGe-HBTs can achieve cut-off frequency above 100 and 200 GHz, respectively [3]. To effectively utilize both types of devices, one popular approach is to develop BiCMOS processes that allow more flexibility and integration of more complex circuits on the same chip. These are the main assumptions for one to be able to design the applicable RF chipset for the proposed M-sequence approach. Principally, the desired RF circuits must feature among other things wideband input and output matching, typically to a 50 Ω environment and simultaneously must show low power consumption by speed compliance. Moreover, on the receiver side these must show flat gain over the entire bandwidth, good linearity and minimum noise contribution.

Basic M-Sequence approach

Figure 1 show the basic structure of the M-Sequence based UWB sensor system. A single tone RF generator (master clock) pushes a digital shift register. If this shift registers disposes of appropriate feedbacks, it provides the M-Sequence (Maximum Length Binary Sequence) at its output. This signal serves as a test signal. It is periodic stimulus. The usable bandwidth, in order to avoid the aliasing, is ≤ fc/2, where fc is the master RF-clock rate. On the receiver side, the signal of interest is captured by a track and hold (T&H) circuit operating in an under sampling mode so that low cost ADCs and acquisition memories can be applied.

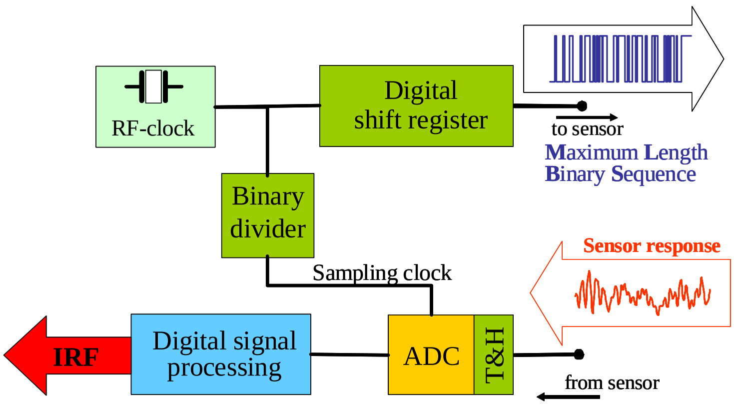

Figure 1 **Basic M-Sequence concept.**

The key-RF-components of the system, the M-Sequence Generator, the binary divider and the T&H-circuit are manufactured in low cost, high performance 0.25µm SiGe:C BiCMOS Semi-conductor technology.

Extended M-Sequence approach

Some sensor applications and current standardization order exactly defined operation band. That is why the basic M-Sequence concept must be extended with an up-down frequency converter (see Fig. 2).

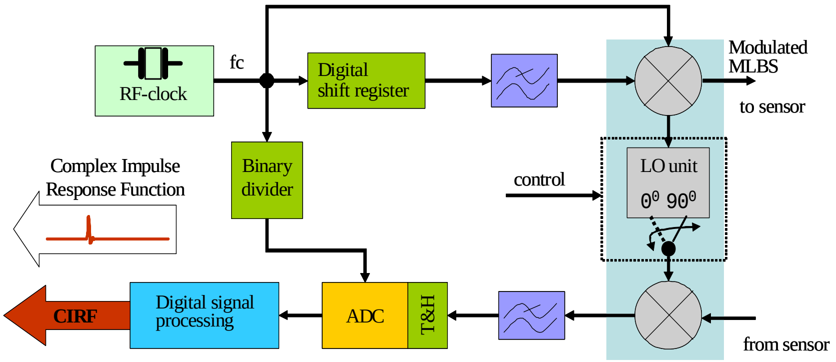

Figure 2 **Modulated M-Sequence & Switched IQ sensor system**

On the transmitter side, the spectrum of the original M-Sequence is shifted to a higher spectral band by mixing it with the carrier signal. For simplicity, we fixed the carrier frequency to fc (for the first tests to7GHz). Therefore the main part of the stimulation energy is concentrated in the double-sided frequency band of fc–fc/2 to fc+fc/2 (3.5 – 10.5GHz). On the receiver side, the captured signal is directly IQ-down-converted back to the complex base-band CIR (Complex Impulse Response). The classical parallel IQ-demodulator concept was rejected because of the expected problems with complex response symmetry and stability. Instead, we realized a new sequential IQ-architecture. Here the phase of the LO signal is sequentially switched by $0^0/90^0$ (see Fig. 2). The switching sequence is synchronous to the T&H and the ADC clock. Therefore, a serial I and Q data stream is produced. The data stream is two times slower in its sampling rate compared to the base-band mode. Such the improved system can be easily extended to operate in the arbitrary frequency band.

Because of the growing demand in using unlicensed bandwidths specifically around 60 GHz for high data rate wireless communications, the first simple experiments have been undertaken with the mm-Wave up-down converter (@ HHI Berlin and @ HUT Helsinki) connected to the extended M-Sequence system presented above.

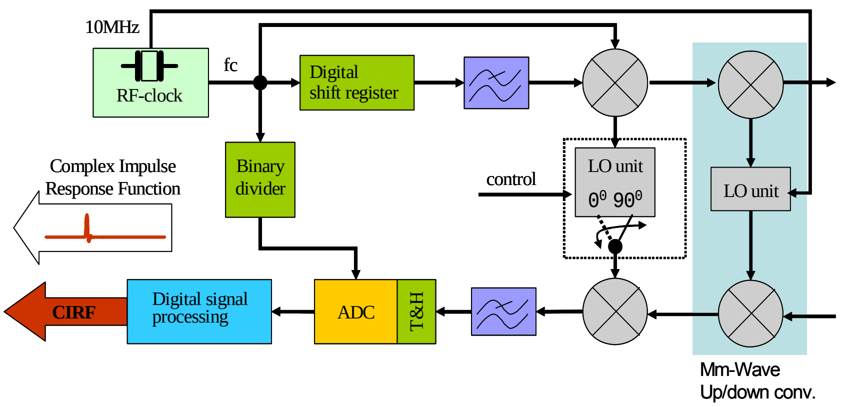

Figure 3 **Modulated M-Sequence & Switched IQ sensor system with mm-wave up-down Converter**

Firstly the functionality of such hardware constellation was checked – with success. Afterwards as mentioned above, we have made the first simple experiments, among others the influence of the real time human body activity in the mm-wave channel was investigated. In this case series of three different scenarios was realized: one, two and three persons were passing the LOS in the standard office room. The 50-sec-long measurements of the channel impulse response have been recorded. Simple normalized attenuation as the ratio of the received energy in the LOS case to the received energy when the person(s) are passing the LOS (NLOS case) was calculated and presented at "Statusseminar Mobile Kommunikation und GaN-Elektronik", Erlangen 2006 [6].

Enhanced M-Sequence system

Basic drawbacks of the extended approaches presented above are the need for anti-aliasing filters and the absence of signal energy in the base band. The last issue can be addressed by appropriately adding the up-mixed and the baseband M-sequence.

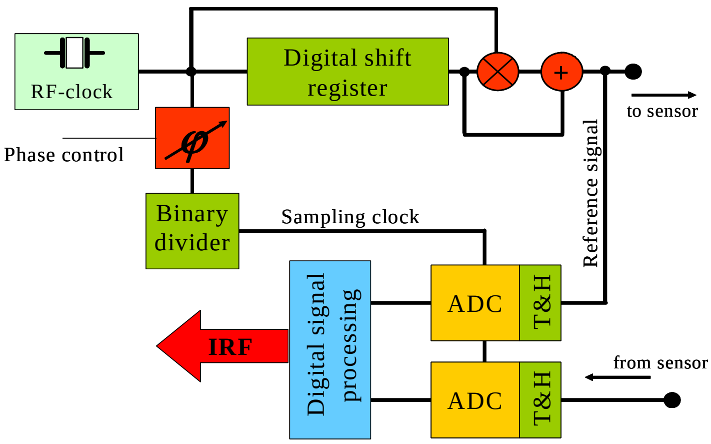

Figure 4 **Enhanced M-Sequence system.**

Since the stimulus signal now spans the whole frequency band from near DC to about 1.5fc, down-mixing and baseband filters can no longer be used. Analogue signal bandwidth is now limited by transmitter bandwidth as well as the input bandwidth of the T&H circuit in the receiver. If we properly control the sample point in the T&H circuit due a delay control stage placed for example before the clock divider, it is possible to increase the equivalent sampling rate until the sampling theorem is satisfied again. In this manner the receiver acquires more then one sample per M-Sequence chip as common in basic approach [1]. Such the receiver operates in 'pseudo' over sampling mode. Consequently, the measurement time increases.

Because of the very wide bandwidth of the new system and the absence of anti-aliasing filters, one is extremely flexible in choosing the measurement's frequency band by digital filtering of the acquired data. Filter types can be arbitrarily chosen without changing any hardware.

Conclusion

Current radio regulation activities and new cost effective measurement principles will promote the application of ultra wideband devices for a great deal of applications operating in the GHz range. The article presents three variants of an ultra wideband measurement device dealing with M-Sequence stimulation signals.

Finally, the new sensor idea realization would not be possible without parallel advance in software for the design, layout, simulation and verification of the device on the one hand and the strong mathematical apparatus concerning signal processing of the captured data on the other hand.

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