A ROBUST ULTRA BROADBAND WIRELESS COMMUNICATION SYSTEM USING SAW CHIRPED DELAY LINES

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ABSTRACT

Design and performance of SAW chirped delay lines on $LiTaO_3$-X112rotY for a wireless communication system are presented. Center frequency bandwidth and chirp rate are 350 MHz, 80 MHz, and ± 20 MHz/s, respectively. An optimized square-root weighting was chosen to reduce the sidelobes of the compressed pulse to -42 dB compared to the correlation peak. The chirp filters have been deployed in a hardware demonstrator for a wireless indoor communication system for data rates of a few MBit/s. Limiting factors for the data rate according to simulations and measurements are mainly the intersymbol interference due to the time-overlapping of consecutive symbols and to a lower extent the multipath propagation.

INTRODUCTION

The wireless communications market is rapidly growing. The major driving force is the field of personal communications (e.g., cellular or cordless phone systems). Today, surface acoustic wave (SAW) devices are widely used in wireless communication products. Because of their high performance, small size and low cost RF and IF filters are frequently made of SAW devices [1, 2]. These properties make them also well suited for wireless communication in industrial environments. Here the main application is a flexible and mobile data transmission between sensors, actuators, autonomous vehicles, robots, and controller units. The major issue is a robust communication link despite the hostile electromagnetic environment which includes severe electromagnetic emissions from other devices as well as heavy distortions due to multipath propagation. Under such difficult conditions the use of a wideband ($>$ 50 MHz) spread spectrum system with high processing gain is favorable. Because of its simplicity a chirp spread spectrum system is an attractive solution. The key functions of such a system are the generation of the transmitted chirp signal (FM signal) and the correlation process in the receiver. Both functions are easily accomplished by using SAW chirped delay lines. They provide a simple and cost effective solution for a high-speed wireless communication system for indoor, office, and industrial environments. The system uses binary orthogonal keying (BOK) by making use of the quasi-orthogonality of up- and down chirp signals which leads to a very robust communication link. This contribution describes the design, technology, and measured results of the used SAW chirped delay lines. The proposed communication system and simulation results are presented and first measurements obtained with a hardware demonstrator are given.

THE SAW CHIRPED DELAY LINES

Up- and down-chirp filters have been designed and fabricated from $LiTaO_3$-X112rotY substrate using standard optical lithography technique. As metalization a layer of 72 nm thick aluminum has been deployed. The filters have a center frequency and bandwidth of 348.8 MHz and 80 MHz, respectively. According to [3] two apodized transducers were used. A split finger arrangement was chosen to avoid internal reflections. The chip size is 11.8×2.0 mm^2. An optimized square-root weighting of the magnitude of the filter transfer-function was employed to reduce the sidelobes of the compressed pulse to -42 dB compared to the correlation peak. Measurement results of the

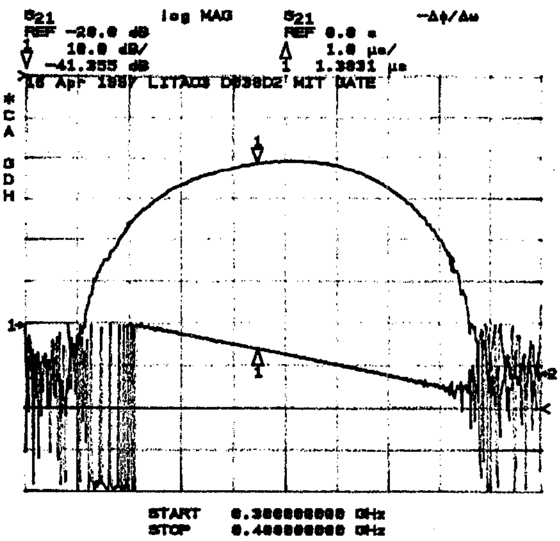

Figure 1: Measured transfer function and group delay of an optimized square -root weighted down-chirp filter.

transfer function and the group delay of a down-chirp filter are shown in Fig 1. The chirp rate of the filters is about 40 MHz/s which results in a dispersion time of about 2 μs. This corresponds to a time-bandwidth product of 22 dB.

SYSTEM DESIGN

The principle of the BOK wireless communication in the time-frequency plane is shown in Fig. 2. A linear (up)-chirp signal is represented by

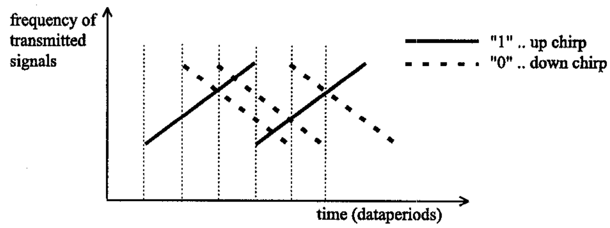

Figure 2: Principal schematic of the BOK wireless communication system.

$$h(t) = a(t) \cos\left[2\pi f_{\hat{m}} + \pi\mu t^2 + \Theta_0\right] \quad (1)$$

with the amplitude $a(t)$ and

$$f_{\hat{m}} = f_m - |\mu| \left(\frac{T}{2} + \tau_0\right) \quad (2)$$

where T, f_m, μ, and τ_0 are the chirp signal duration, center frequency, chirp rate, and time delay, respectively. Depending on the sign of the chirp rate μ we get an up-chirp ($\mu > 0$) or a down-chirp signal ($\mu < 0$). As can be derived from eq. (1) an up-chirp filter is the matched filter for a down-chirp signal and vice versa. Up- and down-chirp signals are almost orthogonal [5]. The chirp filters in the transmitter (expanders) are stimulated with a short IF-pulse. The expanders respond with a 2 μs long chirp-signal whose frequency varies linear with time, e.g., from 308.8 MHz to 388.8 MHz for the up-chirp filter. For BOK modulation either an up- or a down-chirp is transmitted depending on the value of the binary data symbol. Due to the quasi-orthogonality of the chirp signals they can be added almost without interfering. To increase the data rate overlapping chirps are used which means that a consecutive IF-pulse stimulates a new chirp before the previous 2 μs long chirp has ended. The IF-signal is upconverted to 2.45 GHz, amplified, and transmitted. The received signal is fed into both chirp filters after mixing. At the output of each receiver filter the short correlation peaks appear.

SIMULATION RESULTS

A typical simulation result is shown in Fig. 3. Here the output of the receiver chirp-filters after

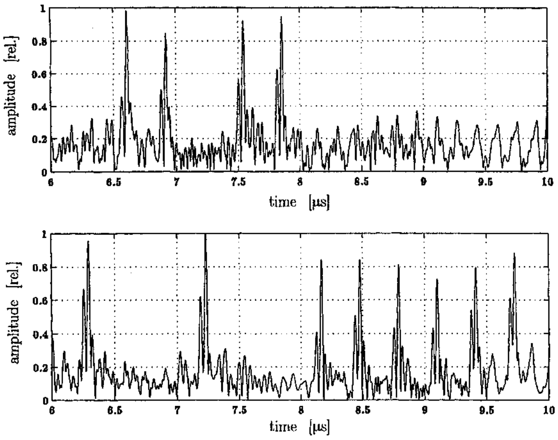

Figure 3: Simulated output of the receiver chirp filters after envelope detection.

envelope detection is depicted. Both the chirp filters and the radio cannel model are implemented as discrete frequency transfer functions and the linear simulation is carried out in baseband with the MATLAB software. The effect of the multipath fading radio channel is modeled with the simulation software SIRCIM which has proven to be a reliable emulation tool [4]. As up- and down-chirp signals are only quasi-orthogonal, disturbing output signals at the receiver filters occur. E.g., if an up-chirp signal is compressed in an up-chirp filter (which is the matched filter for a down-chirp signal) a small crosscorrelation peak appear at the filter output. These disturbances from the intersymbol interference (ISI) between up- and down-chirp grow as the overlapping of consecutive chirps increases. The ISI mainly limits the actual data rate. As can be seen in Fig. 3 the distortions due to the ISI are increasing if chirps of one kind are not transmitted over several symbol periods. This case must be prevented by using proper source coding. To a somewhat lower extent the time dispersion due to the multipath fading channel is another limiting factor for the maximum data rate.

EXPERIMENTAL RESULTS

A hardware demonstrator has been set up to prove the feasibility of the proposed system as well as to demonstrate its robustness for indoor data communication. The schematic of the demonstrator is depicted in Fig. 4. After combin-

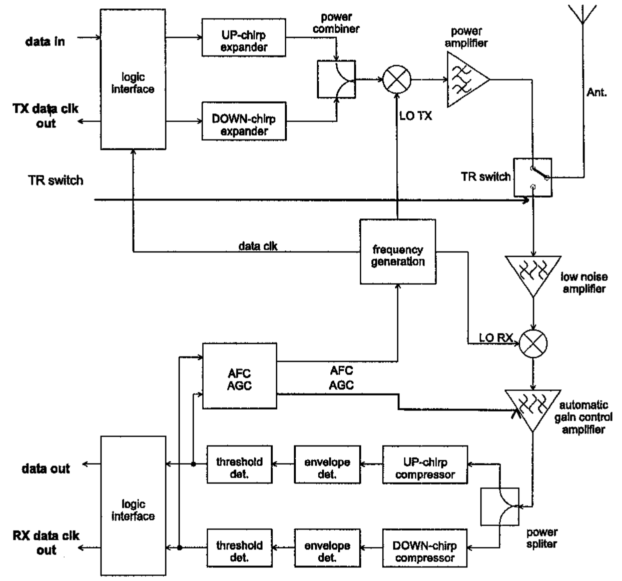

Figure 4: Schematic of the hardware demonstrator.

ing the two orthogonal chirp-signals the IF-signal is converted to the RF band (the 2.45 GHz ISM-band), amplified and fed into the antenna. The transmit power was +13 dBm. We used time duplex operation for the system. A Tx/Rx switch isolates the transmiter from the receiver path. A low noise amplifier together with a bandpass filter prepares the received signal prior to the mixer. The down converted received signal is fed into the matched dispersive SAW delay lines. The signal is compressed in time, enhancing the amplitude for sampling. After a simple but reliable envelope detector the signal is processed by an adaptive threshold decision device followed by the interface logic as well as automatic frequency and automatic gain control circuits. The output of the receiver filter after envelope detection for a data rate of about 3.2 MBit/s is shown in Fig. 5. The simulation and measurement results indicate that for data rates of a few MBit/s and typical delay spreads in indoor environments the simple

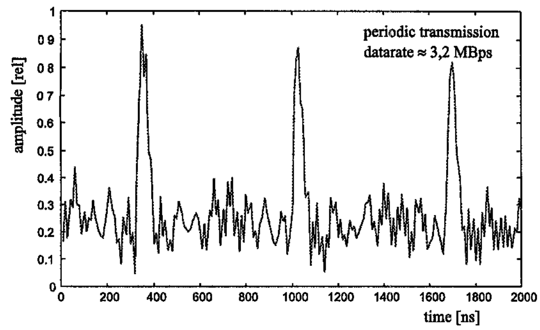

Figure 5: Measured output of the receiver filter after envelope detection.

threshold device in the receiver can be used. For higher data rates more elaborate receiver structures like time-windowing, the Rake-receiver or higher-order modulation have to be used and the weighting of the chirp filters should be optimized concerning pulse energy, sidelobe suppression, and crosscorrelation.

CONCLUSION

Measurement and simulation results of a robust ultra broadband wireless communication system for indoor environments were presented. The system makes use of SAW chirped delay lines for simple and cost effective generation and matched filtering of wideband (80 MHz) chirp signals. The chirp signals make the transmission secure against distortions from multipath fading. The major limiting factor for the data rate therefore is the intersymbol interference due to time-overlapping of consecutive symbols.

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