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Multi-User Capability of an FM IR-UWB System

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Introduction

Regulation authorities worldwide allocated or are about to allocate large frequency bands for the use of ultra-wideband (UWB) technology. The first to announce frequency masks for the unlicensed use of UWB was the Federal Communications Commission (FCC) in 2002, which opened a spectrum from 3.1–10.6 GHz at a maximum mean effective isotropic radiated power (EIRP) spectral density of -41.3 dBm/MHz [1]. One possible implementation for UWB technology is the so called impulse radio (IR) technique, where short time domain impulses, occupying all or part of the allocated UWB band, are applied.

Current proposed modulation schemes for IR-UWB are a discrete and quantized pulse amplitude or pulse position modulation. Here each impulse contains the digital information of a bit (or chip). In contrast to these digital modulation schemes, in [2] an analog modulation of the impulse's repetition rate was presented. It is advantageous especially when the transmitted information, like speech or sensor data, is already present in analog form, and therefore avoids the analog-to-digital conversion of this information. The system proposed there was implemented using a Si/SiGe fifth derivative impulse generator, an ultra-wideband Si/SiGe low-noise amplifier, two UWB patch antennas, a half-wave Schottky diode rectifier, a signal source with a frequency modulation option and a test receiver for demodulation. The system was validated by detailed measurements, proving the concept of operation and showing the potential of this communication system.

Fig. 1: Block diagram of the frequency modulated IR-UWB transceiver system.

In this work an investigation for a multi-user scenario using the proposed modulation scheme is presented. The test system is introduced and the feasibility of a multi-user setting is practically shown along with the restrictions that apply for the spacing of user channels.

Basic FM IR-UWB System

A block diagram of the proposed transmission system can be seen in Fig. 1. In the transmitter the analog information is converted by a modulator to a frequency modulated (FM) signal. This FM signal is used as the trigger for the impulse generator, where at every rising edge an impulse is generated. This results in a frequency modulated impulse train, containing the generated analog information signal. Fig. 2 (left) illustrates the time domain signal evolution in the transmitter. Fig. 2 (right) shows a simulation of a general UWB transmit signal spectrum. The envelope of the line spectrum is given by the output time domain shape of the impulse generator.

Fig. 2: Illustration of the signals at the output of the transmitter's function blocks (frequency deviation not to scale) (left). Example spectrum of a UWB transmit signal (right).

The spectrum can be made compliant with country specific regulations by a change of the impulse shape. The envelope is divided by spectral lines, which are induced by the constant repetition of the impulses. In case of an unmodulated impulse train the spectral lines have no spectral broadening. When a frequency modulation is applied each line widens and its bandwidth can be approximated by a modified Carson bandwidth to

$$B_{FM,N} \approx 2 \cdot N \cdot (\Delta f_T + f_{s,max}) \quad , \quad (1)$$

where Δf_T is the FM deviation, $f_{s,max}$ is the FM rate, i. e. the highest appearing frequency component of the information signal, and N is the order number of the higher harmonic spectral line (cf. [3]). This means the higher in frequency, the larger the broadening of the spectral lines.

Fig. 3: Illustration of the time domain signals appearing in the demodulator (left). Spectral representation of a rectified UWB impulse and illustration of an ideal bandpass filter (right).

To demodulate the information, the received impulse signal is fed to a rectifier, which converts the bandpass limited UWB emission back to the baseband. In Fig. 3 (right) the spectrum of the rectified signal can be seen. The envelope has changed in contrast to the transmitted signal and approaches DC. The spectrum is still divided by spectral lines, where the first harmonic is at the repetition rate frequency and is identical in frequency, FM deviation and FM rate to the FM signal used for triggering in the transmitter. Using a bandpass filter this signal can be extracted, and in an FM demodulator the information signal can finally be recovered. In Fig. 3 (left) the time domain signals appearing in the demodulator can be investigated. [2] provides detailed measurements with a simple test system, which validates the modulation scheme in a practical transmission, using a repetition rate of 100 MHz, an FM deviation of 60 kHz, an FM rate up to 20 kHz and a filter bandwidth in the demodulator of 120 kHz. These settings are based on the settings used in FM radio and have the big advantage that widely available commercial modulator and demodulator components can be reused for FM IR-UWB.

Multi-User Measurement

The proposed modulation method shall be investigated for its multi-user capability. State of the art IR-UWB transmissions propose the use of time division multiplex for correlation-based receivers, or code division multiplex for energy detection or correlation receivers, all with the disadvantage that precise synchronization either in chip or bit-level must be known to the receiver and additional hardware for the code spreading is required. For the FM IR-UWB transceiver the idea is to separate channels by using different impulse repetition rates, which is similar to tune to different FM center frequencies in FM radio, but more complex, due to the entanglement of the impulse spectra from each user. To investigate the minimal necessary frequency spacing of user channels, the influence of the spectral broadening of the higher harmonics according to (1) has to be taken into account. The minimal necessary spacing is investigated by measurements using the proposed test system. Therefore the outputs of two transmitters are connected by a power combiner and fed by cables to the input of the receiver. A block diagram of this setting is seen in Fig. 4. With this setup, the parameters for two users can be individually defined, and the occurring effects characterized in an ideal transmission channel.

Fig. 4: Setup for the multi-user measurement using two transmitters at different repetition rates.

Fig. 5 (left) exhibits a spectral domain measurement at the output of the power combiner. The first transmitter uses a impulse train repetition rate of 100 MHz, seen in the spectral signals at 6.4, 6.5 and 6.6 GHz and the second transmitter a repetition rate of 99.5 MHz, seen in the spectral signals at around 6.37, 6.47 and 6.57 GHz accordingly.

Fig. 5: Spectral domain measurements at the output of the power combiner in RF domain (left) and down-converted at the output of the bandpass filter (right).

Fig. 5 (right) plots a spectral domain measurement at the output of the receiver's bandpass filter. Here the recovered repetition rates of the first and second transmitter at 100 MHz and 99.5 MHz, respectively, are visible. By choosing the corresponding center frequency in the demodulator, either the first or the second transmitted information signal can be demodulated. The spurs in the vicinity of the main spectral signals in Fig. 5 (right) are mixing products due to the rectification. To determine the minimal necessary channel spacing of two closely spaced transmitting systems,

the first transmitter is kept at a fixed repetition rate, while the one of the second transmitter is varied. Measurements are done for fixed repetition rates of 95 MHz and 100 MHz. In both transmitters the FM deviation is set to 60 kHz. For the first transmitter an FM rate of either a sinusoidal signal at 2 kHz and 20 kHz is applied, while for the second transmitter an FM rate of either 1.95 kHz and 19.95 kHz is applied. The small frequency difference is to avoid interferences in demodulation. In the receiver, the demodulated output signal of the first user is monitored, which is for the single user case a pure sinusoidal at either 2 kHz or 20 kHz. When the repetition rate difference of the two transmitters is decreasing, the pure sinusoidal is distorted, which can be seen in spurs in the demodulated spectrum. A measure for these distortions is the spurious free dynamic range (SFDR). A comparison of the measurements of SFDR versus the repetition rate difference of the two transmitters can be seen in Fig. 6.

Fig. 6: Spurious free dynamic range of the information signal versus the repetition rate difference of two users for an FM rate of 2 kHz (left) and 20 kHz (right).

It is evident that no difference is visible for the two repetition rates at 100 MHz and 95 MHz. To achieve, e. g. a SFDR of 30 dB in the information signal, it is necessary to choose a repetition rate separation of larger than 150 kHz for an FM rate of 2 kHz and a separation of larger than 200 kHz for an FM rate of 20 kHz. Keeping in mind that the Carson bandwidth of a conventional FM radio system is 124 kHz for an FM rate of 2 kHz and 160 kHz for 20 kHz, the influence due to the spectral broadening can be neglected and users can be separated like in conventional FM radio.

Conclusion

In this work it was discussed and experimentally shown that the FM IR-UWB transmission scheme can be operated in a multi-user environment by a simple change of repetition rate in the two transmitters. It was found that the minimal necessary user spacing is not influenced by the broadening of higher harmonics and is similar to a conventional FM radio transmission.

References:

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