FULLY INTEGRATED CMOS MULTI-GBPS FREE SPACE OPTICAL COMMUNICATION RECEIVERS

By

Behrooz Nakhkoob Niasari

An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: ELECTRICAL ENGINEERING

The original of the complete thesis is on file
in the Rensselaer Polytechnic Institute Library

Examining Committee:

Professor Mona M. Hella, Thesis Adviser
Professor Michael Shur, Member
Professor Gary Saulnier, Member
Professor Masashi Yamaguchi, Member

Rensselaer Polytechnic Institute
Troy, New York

December 2012

ABSTRACT

With the ever-increasing demand for faster communication, conventional bandwidth limited radio frequency RF links have arguably reached their performance limits. Wireless optical communication is a promising technology that can address such a demand while adding other advantages such as low power consumption per transmitted bit, higher security, and less vulnerability to electromagnetic interference compared to RF. However, the main shortcoming of such a communication link is the requirement of direct Line of Sight (LOS). Other challenges in optical wireless receivers include a weak received signal due to the low transmitted power of laser diodes and the cost of integrating photodiodes in the same technology with the analog processing circuitry. In this thesis, we investigate the implementation of fully integrated wireless optical receivers that are capable of high speed communication between portable objects with limited mobility for indoor scenarios. Typical applications are future ultra wide-band wireless local area networks, secure high speed wireless links in adjacent rooms in a building, and wireless connectivity of HDMI (High-Definition Multimedia Interface) signal for high definition TV.

The thesis starts with a system design for electronic beam steering. Two novel system designs are introduced based on a spherical optical antenna and imaging diversity architecture. Next, the design of high speed photodiodes PDs to be integrated with the receiving circuits in low cost Si-CMOS technology is investigated. The speed bottleneck of CMOS photodiodes is studied thoroughly and several high speed photodiodes are designed to provide a bandwidth that exceeds by orders of magnitude the bandwidth of a typical PN junction PD.

For the analog processing circuitry, low noise, low power and wideband optical communications integrated circuits are investigated in CMOS technology. A fully differential receiver is fabricated in IBM 130 nm CMOS technology. The receiver is capable of 5 Gbps communication while consuming 65 mW. The receiver's sensitivity is 2.8 μA for a Bit Error Rate (BER) of 10^{-12}, while the output signal is 900 mV p-p over a 50 Ω matched load. The presented results are comparable to the best

reported sensitivity in published optical receivers while consuming less power and less chip area.

The implementation of the single optical receiver is extended to an imaging array capable of line of sight LOS tracking. The receiver is composed of a 3×3 matrix of Spatially Modulated Light SML photodiodes, a high sensitivity 6 $K\Omega$ TIA, and a novel adaptive equalizer which compensates for the roll off in the optical amplifier transfer function as a result of the lower bandwidth of photodiodes as well as the change in the number of activated photodiodes at the input and their corresponding capacitances. Thus, the proposed equalizer maintains a high bandwidth in the optical link regardless of the number of PDs in line of sight with the transmitter. Using an edge detector/rectifier block, the data rate of the input signal is detected, which in turn tunes a variable low pass/high pass filter for balancing the power spectrum of the signal. Mathematical analysis of different blocks in the imaging receiver as well as circuit level characterizations are done to verify the receiver's functionality. A prototype chip is fabricated in 130 nm CMOS technology. The imaging receiver is capable of 5 Gbps communication while consuming 97 mW and providing a 750 mV p-p output voltage over a matched load. The total die area including the bond pads is 870×1400 μm^2. Such a high speed receiver paves the way for ultra-high speed wireless optical communication links that outperform current radio frequency and future mm-wave links at lower power consumption for indoor applications.