PERFORMANCE OF PHOTONIC OVERSAMPLED ANALOG-TO-DIGITAL CONVERTERS

by

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Supervisors: Prof. Jesper Munch and Dr. Kerry Corbett.

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Abstract

In an increasingly digital world, the need for high speed and high fidelity analog-to-digital (A/D) converters is paramount. Performance improvements in electronic A/Ds have not kept pace with demand, hence the need to consider alternative technologies. One such technology is photonics, as it takes advantage of optical sampling, high speed optical switches and low cross-talk interconnects. Optical sampling derives its advantage from the application of ultra low timing jitter (<100fs) mode locked lasers utilised to provide high speed clock pulses.

In this thesis the feasibility and simulated performance of three different types of photonic oversampled A/D converters was investigated. The first, and simplest design is that of oversampled pulse-code-modulation (PCM), where a 2-level photonic comparator is used to sample the analog input at a frequency much greater than the Nyquist frequency. Subsequent low pass filtering produces a digital representation of the input. The other two architectures that were investigated are the first-order sigma-delta and error diffusion, which add one level of error correction to the PCM technique. These two architectures require the functional elements of a subtractor, comparator and delay. The photonic comparator and subtractor functionality was provided by Self-Electro-Optic Effect devices (SEED) based upon multiple quantum well (MQW) p-i-n devices.

To facilitate calculation of the performance of the different architectures and aid in device design, a simulation of SEED operation based upon experimental data was developed. The simulation's accuracy was demonstrated by agreement with the results from experimental S-SEED switching and optical subtraction. To emphasize the utility of the model, the simulation was subsequently used to demonstrate tristability of an S-SEED and critical slowing down in a bistable S-SEED. These effects were experimentally verified.

To provide enhanced comparator contrast ratio and subtractor dynamic range, resonantly enhanced microcavity multiple quantum well (MQW) p-i-n devices were designed and grown by MOCVD. The operation of the subtractor and comparator was experimentally demonstrated and utilising temperature tuning, optimised per-

formance was achieved with devices from the same wafer. Furthermore, the inclusion of gain was shown to improve the subtractor performance to that demanded by the sigma-delta.

The constraints on each architecture imposed by the unipolar nature of the light intensity were derived and the sigma delta architecture was shown to be superior to the error diffusion for a photonic implementation. Using the numerical simulation based upon experimentally derived data, the entire sigma delta architecture was simulated to calculate the expected performance. The signal-to-quantisation-noise ratio (SQNR) was calculated as a function input amplitude and a peak SQNR of 54dB was obtained for an oversampling ratio of 100.

List of Symbols

Throughout this thesis, several symbols will be used repeatedly to represent specific quantities or parameters, the following is a list of these symbols and short descriptions for the readers convenience. This list is not exhaustive but every effort has been made to maintain conformity of symbols used here. Wherever possible standard symbols and notation have been used which appear in most texts.

A/D	...	Analog to Digital Converter
$AlAs$	...	Aluminium Arsenide
$AlGaAs$	...	Aluminium Gallium Arsenide
AR	...	Anti-Reflection
a, L_w	...	Width of quantum well
a_0	...	Bohr radius
α	...	Absorption coefficient
C	...	Capacitance
CR	...	Contrast ratio
c	...	Speed of light in vacuum
Δ	...	Hysteresis width
E_g	...	Bandgap in eV
E_c	...	Minimum conduction band energy
E_v	...	Maximum valence band energy
E_b	...	Exciton binding energy
e	...	Charge of an electron
e_i	...	Error in comparison operation
ϵ_0	...	Permittivity of free space
ϵ_r	...	Relative permittivity
f_B, f_0	...	Input bandwidth
f_d	...	Dither frequency
f_s	...	Sampling frequency
$GaAs$	...	Gallium Arsenide

$GSPS$	...	Giga Samples per Second
G	...	Gain
$GPIB$	...	General Purpose Interface Bus
$\hbar$	...	Planck's constant
η	...	Quantum efficiency
I	...	Current
φ	...	Phase
φ_n	...	Wavefunction of quantum well
k	...	Extinction coefficient
l	...	Geometric pathlength in a laser crystal
λ	...	Wavelength
m^*	...	Effective mass
$MSPS$	...	Mega Samples per Second
$MOCVD$	...	Metal-Organo Chemical Vapour Deposition
MBE	...	Molecular Beam Epitaxy
MQW	...	Multiple Quantum Well
n	...	Refractive index
N	...	Number of quantum wells
n_{3D}	...	Density of states in for a particle in 3 dimensions
n_{2D}	...	Density of states in for a particle in 2 dimensions
NID	...	Non intentionally doped
ND	...	Neutral Density

OSR	...	Oversampling ratio
P	...	Power
$P_{\theta L}$	...	Lower bound of hysteresis
$P_{\theta H}$	...	Upper bound of hysteresis
P_{θ}	...	Midpoint of hysteresis width
PCM	...	Pulse Code Modulation
q_i	...	Output signal of A/D comparator
Q_L	...	Low output of comparator
Q_H	...	High output of comparator
$QCSE$	...	Quantum Confined Stark Effect
R	...	Reflectivity
$REAM$	...	Reflection Electro-Absorption Modulator
S	...	Responsivity
$SFDR$	...	Spur Free Dynamic Range
$SEED$	...	Self-Electro-Optic Effect Device
$S-SEED$	...	Symmetric Self-Electro-Optic Effect Device
$SQNR$	...	Signal to Quantisation Noise Ratio
t	...	Transmission
u_i	...	Input signal to A/D comparator
V_0	...	Applied SEED voltage
x	...	Input signal to A/D

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