

Table Of Contents

Acknowledgements	III
Abstract	IV
Table of Contents	V
List of Figures	VI
Glossary of Acronyms	VII
1. Introduction	1
1.1 Background and motivation	1
1.2 Thesis outline	5
2. Theory of Optical Phase locked loops (OPLLs)	7
2.1 Principle of operation	7
2.2. Time domain analysis	8
2.3 Frequency domain analysis	10
2.3.1 Transfer function method	10
2.3.2 Acquisition and holding range	12
2.3.3 Bode plot and stability criterion	13
2.4 Loop noise characterization	14
2.5 Practical limitations of the loop bandwidth	18
2.5.1 The non-negligible loop delay	18
2.5.2 The non-uniform frequency modulation response of SCLs	22
3. Experimental study and optimization of OPLLs	27

3.1. Measurement of the FM response	27
3.1.1 Analysis of the FM response measurement system	28
3.1.2 Experimental measurement	32
3.2. Phase lock of different lasers	36
3.2.1 Phase lock of JDSU DFB SCLs	37
3.2.2 Estimation of the residual differential phase error	38
3.2.3 Phase lock of the QPC MOPAs	39
3.2.4 Phase lock of the IPS external cavity lasers	40
3.3. Optimization with compensation circuits	41
3.3.1 Lead-lag filter to increase the phase margin	42
3.3.2 Passive lag-lead filter to increase the holding range	46
3.3.3 Active lag-lead filter to increase holding range	50
3.3.4 Aided acquisition circuit to increase the acquisition range	52
3.4 Conclusion	53
4. Application of OPLLs in coherent beam combining	55
4.1 Introduction of coherent beam combining	55
4.1.1 Spectral beam combining vs coherent beam combining	55
4.1.2 Tiled-aperture and filled-aperture CBC	56
4.1.3 Methods to obtain mutual coherence	57
4.2 Synchronizing two SCLs with OPLLs	59
4.3 Correction for the optical path-length variation	63
4.3.1 Phase control using an RF phase shifter	61

4.3.2 Phase control using an RF VCO	67
5. Analysis of the scalability of a cascaded filled-aperture coherent beam combining system	78
5.1 Introduction	78
5.2 Combining efficiency of the filled-aperture CBC scheme	79
5.2.1 Effect of OPLLs residual phase noise	81
5.2.2 Effect of frequency jitter of the VCO	84
5.2.3 Effect of phase front deformation due to optical components	88
5.2.4 Effect of intensity noise	93
5.2.5 Effect of fiber amplifier phase noise	95
5.3 Conclusion	99
6. Coherence cloning using OPLLs	101
6.1 Introduction	101
6.2 Phase noise and frequency stability of a single frequency laser	102
6.2.1 Phase and frequency fluctuations of an oscillator	102
6.2.2 Power spectral density of the phase or frequency fluctuation	103
6.2.3 Autocorrelation, coherence and linewidth of an optical field	104
6.2.4 Example: white frequency noise	105
6.3 Experimental methods of measuring the frequency stability	106
6.3.1 Time domain measurement of the frequency fluctuation	107
6.3.2 Frequency domain measurement	108
6.3.2.1 Power spectral density of the frequency noise	109

6.3.2.2 Self-delayed heterodyne measurement of the lineshape	110
6.4 Coherence cloning using OPLLs	111
6.5. Experimental measurement	116
6.5.1 Measurement of the Agilent laser	116
6.5.1.1 RIN of the Agilent laser	116
6.5.1.2 Frequency noise of the Agilent laser	118
6.5.1.3 Lineshape of the Agilent laser	119
6.5.2 Measurement of the free-running and locked JDSU DFB laser	120
6.5.3 Measurement of the NP fiber laser and the locked JDSU laser	123
6.5.4 Conclusion	129
7. Conclusion	130
References	134