Abstract

A phase lock loop (PLL) is a negative feedback control system that fixes the frequency and phase of a local oscillator in relation to the frequency and phase of a "reference" signal. Electronic phase lock loop has been studied for more than half a century and has been widely used for clock recovery and generation, spread spectrum, clock distribution, jitter and noise reduction.

However, the study and applications of Optical phase lock loop (OPLL), the counterpart of electronic PLL in the optical domain, are far from the same level of progress as electronic PLL. Part of the reason is that most applications of optical signals so far do not require the precise control of the phase of the optical signals; another reason is that most implemented OPLLs are based on either gas lasers or solid state lasers, whose bulky size and high cost inhibit the applications of OPLLs.

Today semiconductor lasers are being used in numerous applications due to their low cost, small size, and high efficiency. OPLLs based on SCLs were once studied in the late 1980s and early 1990s for coherent optical communication purposes. However, at that time, a few technical difficulties associated with SCLs were not completely solved and the technology was not mature. Since the invention of Erbium doped fiber amplifier, direct detection has become the dominant technology for telecommunication and research on SCL OPLLs has declined abruptly.

In the last decade, heavy investment in telecom has significantly improved the performance of SCLs. Emerging applications have drawn the attention of researchers to phase coherent optics again. In this thesis, I report on a study of OPLLs using commercial SCLs, and explore the applications in emerging fields other than telecommunication.

The first part introduces the theory of OPLLs and presents the experimental study of OPLLs made from different commercial SCLs. The non-uniform FM response of single-section SCLs and the non-negligible loop delay are identified as the critical factors which

limit the performance of the OPLLs. In order to improve the performance of OPLLs, electronic compensations using filter designs are also discussed and studied.

In the second part, the application of OPLLs in coherent beam combining is firstly studied. Using OPLLs, an array of slave lasers can be phase locked to the same master laser at the same frequency, their outputs can then be coherently combined. The phase variations of the element beams due to the optical path-length variations in fibers can be further corrected for by using multi-level OPLLs. This approach eliminates the use of the optical phase/frequency shifters conventionally required in a coherent beam combining system. Proof of principle experiments are demonstrated using the filled-aperture combining scheme. Furthermore, I will discuss the scalability of a cascaded filled-aperture combining system for the combination of a large number of lasers.

The second application using OPLLs explored in this work is to clone the superior coherence property of a high-quality master laser to inexpensive SCLs. First, I will describe the theory of coherence transfer using OPLLs. I will then present the experimental measurements of the linewidths and frequency noises of the master laser, the free-running and locked slave lasers.

The thesis concludes by identifying future works that need to be done to advance the development of this technology.