**Introduction**

Semiconductor lasers (SLs) are a subset of laser diodes that have been extensively studies since the first demonstration of laser oscillations in 1960. Particularly, SLs are laser diodes that are electrically pumped in order to achieve population inversion so that through stimulated emission we may maintain amplification. Attention has been particularly drawn to SLs for their ability to provide insight into nonlinear and chaotic dynamics, and further promising technology with applications in image sensing, fibre optic communication, and spectroscopy. These applications in particular prove to have viable potential for vastly improving communication capabilities and security, and therefore the development and understanding of this technology is extremely useful.

While the application of optical fibre is mostly hidden, due to their attractive characteristics their use and implementation are vast and rapidly growing. More broadly, laser diodes, almost uniquely, possess the property of being extremely perceptible to optical perturbations, which leads to the ability to achieve quite high modulation of the laser. In combination with optical fibre, it is possible to direct and guide the laser light produced from SL laser diodes, resulting in superior methods for telecommunication compared with standard methods. Optical fibre in combination with laser diodes provide advantages in long distance communication, especially because of their ability to achieve low losses of information over long distances and having a high insensitivity to perturbations caused by external sources. Due to the impulse of interest and development of this technology, a growing global implementation of optical fibre has led to most forms of networks transitioning to the superior communication method, specifically residential networks through the ‘*Fibre To The Home’* initiative.

It is possible to observe that by coupling a laser to optical fibre, the laser diode may be led to dynamical regimes where the light is completely unstable. Depending on the intensity of the laser, it may be possible to observe periodic oscillations with many frequencies or even chaotic solutions. It is understood that these behaviours are driven by a phenomenon termed optical feedback, due to the reflectivity of the surface which the laser is connected to. While the chaos may appear random, it is understood through chaos theory that this behaviour is indeed deterministic, and that a when a system has enough dimensions, it may have the potential to bifurcate into complex dynamics, such as chaotic solutions.

**Semiconductor Laser Physics**

Briefly, it may be useful to delve into describing the principles and physics concepts that underpin laser dynamics.

***Possible Dynamics***

Light Amplification by Stimulated Emission of Radiation (LASER) is the phenomenon where light is the result of photons emitted in an active medium through stimulated emission. We know from the Bohr Atomic Model that the energy of an electron in an atom is quantised, opposed to continuous. By considering an atom with only two atomic levels, the ground level ($E\_1$) and an excited state ($E\_2$), it is theoretically only possible for such a system to evolve in three ways:

* **Stimulated Emission:**
* **Spontaneous Emission:**
* **Absorption:**

The suppression and amplification effect of stimulated emission is proportional to the number of electrons in $E\_1$ and $E\_2$, respectively. Laser amplification therefore requires population inversion, that is the number of electrons in $E\_2$ needs to be greater than in $E\_1$.

Semiconductor lasers are composed of an active material, which has the optical gain, and an optical resonator, which feeds back light by its reflectors. The active layers generate the spontaneous emission and amplify a fraction of the spontaneous emission by stimulated emission. Semiconductor lasers have carriers, such as free electrons and holes, only in the vicinity of the band edges. Now electrons in semiconductors tend to stay in low energy states, because states with the lowest energy is most stable. Through stimulated emission, electrons transition to higher energy states, before the electrons in high energy states transit to low energy state in a certain lifetime. When the injection current exceeds the threshold current, laser beams are emitted. Note that through stimulated emission, the photons emitted have the same wavelength, phase, and propagation direction as the input photon, and therefore the laser light is highly monochromatic, bright, coherent, and directional.

***Laser Polarization***

When a laser beam is linearly polarized, the electric field of a laser beam oscillates perpendicularly to the propagation direction. A beam that is circularly polarized means that the laser carries a combination of two light sources that oscillate perpendicularly with respect to the direction which they are traveling. We are able to remove polarization through the use of polarizes in our experimental laser-setup.

**Laser Dynamics**

* Poincare-Bendixon Theorem

**Phase-Conjugate Feedback (PCF)**

The electric field of the output laser beam is phase-conjugated, and then re-injected into the laser cavity.

**PROF System**

**PCF System**

**PRPCFUF System**

**PRPCF System**