Ain Shams University
Faculty of Engineering
Electronics and Communications Department

Narrow Line-width Single Mode Optical Random Fiber Laser

A Thesis

Submitted in partial fulfillment of the requirements of the degree of
Doctor of Philosophy in Electrical Engineering

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Thesis Title: **"Narrow Line-width Single Mode Optical Random Fiber Laser".**

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Degree: **Doctor of Philosophy in Electrical Engineering**

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Statement

This dissertation is submitted to Ain Shams University in partial fulfilment of the Doctor of Philosophy Degree (PhD) in electrical Engineering (Electronics and Communications Department).

The work included in the thesis was carried out by the author in the Department of Electronics and Communications Engineering, Ain Shams University.

No part of this thesis has been submitted for a degree or a qualification at any other university or institute.

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ABSTRACT

In this thesis we report a broadband tunable random fiber laser with ultra narrow line-width single longitudinal mode (SLM), based on Rayleigh backscattering in standard single mode fiber (SMF). The wide tuning range of this SLM fiber based laser over 1500 nm – 1570 nm is demonstrated for the first time to the best of our knowledge, with a line-width of 4.5–30 kHz. The tuning is achieved using a tunable bandpass Fabry–Perot filter, and a semiconductor optical amplifier (SOA) is used as the wide-bandwidth gain medium in a linear cavity configuration. A numerical model is also developed accessing the random Rayleigh backscattering throughout the fiber length, and solving the transient time domain SOA rate equations. The model accounts for the dynamics of the SLM random laser building up from transient regime to saturation regime.

We employed the implemented SLM random fiber laser as the core structure to configure a novel tunable dual-wavelength random fiber laser in the C-band with ultra-narrow line-widths. Single longitudinal mode dual wavelengths random fiber laser of tunable separation in range 1.5 – 25 nm (187.5 GHz – 3.12 THz) is presented. In the laser configuration a standard single mode fiber of 2 km length is incorporated as distributed mirrors. Two optical bandpass filters are used for the wavelength selectivity, and two Faraday rotator mirrors are used to stabilize the two lasing wavelengths against fiber random birefringence. The optical signal to noise ratio (OSNR) was measured to be 38 dB. The line-width of the laser was measured to be in range 3 – 11.5 kHz, at different wavelength separations and different SOA pump currents.

We presented another novel tunable dual-wavelength random fiber laser configuration in the C-band with narrower line-widths 2.6 – 3.1 kHz at dual wavelength of 14 nm separation (1550 – 1564 nm). In this configuration, the laser action is contingent on Rayleigh backscattering phenomenon in a single mode fiber of 1 km length, and an Erbium Doped Fiber amplifier (EDFA) for optical amplification. The optical signal to noise ratio (OSNR) is 44 dB. Then a comparison between the results of the two configurations is performed.

Keywords: Random fiber laser, Rayleigh backscattering, Semiconductor optical amplifier, Optical band pass filter, Single longitudinal mode laser, Erbium doped fiber amplifier, Narrow line-width, Dual wavelength laser, terahertz (THz) generation.

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SUMMARY

Random fiber laser (RFL) source is very important for many telecommunication, biomedical and sensing applications especially for DWDM, and high speed switching applications. Dual wavelength RFL has also a strong potential to be one of the most successful optical technologies for Terahertz generation. For such applications, the main interest is to have a wide wavelength-tuning range, ultra-narrow laser line-width, and low cost. Random lasers open the door to implement the system with no complex fabrication technology of conventional lasers, which may initiate a wide variety of new applications. Various configurations have been proposed for RFL utilizing optical components, which are bulky, expensive and entail high pump power in order of few Watts, and long fiber lengths of about 20-100 km. To overcome these challenges, random fiber lasers based on Rayleigh back scattering phenomenon in standard Silica Single Mode Fiber (SMF) have recently attracted a great attention. In a SMF, light is confined in the transverse direction and propagates as the fundamental transverse mode

in the fiber. The intrinsic disorder in the Silica fibers originates from the sub-micron scale inhomogeneity in the refractive index along the fiber axis due to the fiber manufacturing process.

In this thesis we report a broadband tunable random fiber laser with ultra narrow line-width single longitudinal mode, based on Rayleigh backscattering in standard single mode fiber. The wide tuning range of this SLM fiber based laser over 1500 nm – 1570 nm is demonstrated, with a line-width of 4.5–30 kHz. The tuning is achieved using a tunable bandpass Fabry–Perot filter, and a semiconductor optical amplifier (SOA) is used as the wide-bandwidth gain medium in a linear cavity configuration. A numerical model is also developed employing the random Rayleigh backscattering throughout the fiber length, and solving the time domain SOA rate equations. The model accounts for the dynamics of the SLM random laser building up from transient regime to saturation regime.

We employed the implemented SLM random fiber laser as the core structure to configure a novel tunable dual-wavelength random fiber laser in the C-band with ultra-narrow line-widths. Single longitudinal mode dual wavelengths random fiber laser of tunable separation in range 1.5 – 25 nm (187.5 GHz – 3.12 THz) is presented. In the laser configuration a standard single mode fiber of 2 km length is incorporated as distributed mirrors. Two optical bandpass filters are used for the wavelength selectivity, and two Faraday rotator mirrors are used to stabilize the two lasing wavelengths against fiber random birefringence. The optical signal to noise ratio (OSNR) was measured to be 38 dB. The line-width of the laser was measured to be in range 3 – 11.5 kHz, at different wavelength separations and different SOA pump currents.

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The thesis is organized in six chapters as follows:

Chapter 1: Gives a brief introduction of the motivation, objective, major contributions and organization of the thesis.

Chapter 2: Reviews the random laser structures in general and the fiber random laser in particular. A review of the main concept of the Rayleigh backscattering in Silica optical fibers and the impact on the RFL feedback and line-width compression mechanisms is introduced. Moreover a review of the gain mechanisms in RFL structures is carried out. Two gain media; Semiconductor optical amplifier, and Erbium doped amplifier, are reviewed to be utilized as the RFL gain mechanisms. To the best of our knowledge, this is the first RFL implementation utilizing SOA as the gain medium in SLM RFL. The narrow line-width measurement techniques are presented and the Self Delayed Heterodyne method is illustrated. The chapter ends with reviewing the dual wavelength RFL structures.

Chapter 3: Introduces the modeling, characterization, and parameters extraction of the RFL structure different components including the semiconductor optical amplifier, the Rayleigh backscattering in optical fibers, the optical tunable filter and the optical reflectors to be utilized in the structure implementation.

Chapter 4: Presents the study of the single longitudinal mode random fiber laser. The study has two directions: an experimental direction based on a laboratory setup, and a theoretical direction based on the numerical modeling of the equations governing the laser operation. In the experimental part, the output tunable spectrum results, and the I/P characteristics are measured and compared with the I/P characteristics of analytical model. The RFL line-width measurements are performed for different system parameters. The RFL peak

power and wavelength stabilities are also studied. In the theoretical part a numerical model of the complete RFL structure is presented. This model allows analyzing the dynamic behavior of the SLM generation. The ASE is included in the model and its effect during the RFL building up is demonstrated.

Chapter 5: Presents an application of random fiber lasers, the dual-wavelength SLM random fiber laser. A novel structure of tunable dual-wavelength fiber laser is proposed and studied based on two configurations; the gain medium of the first one is an SOA, while the gain medium of the second one is an EDFA. The line-widths of the two modes are measured in each configuration using self-delayed heterodyne technique. A comparison between the two configurations is performed.

Chapter 6: Gives the conclusion of the thesis and introduces several recommendations and suggestions for the future work

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