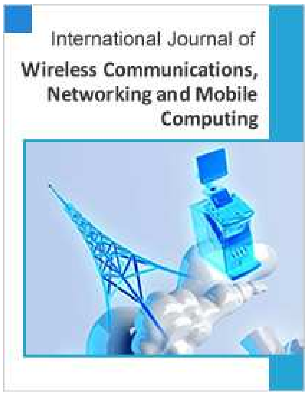
International Journal of Wireless Communications, Networking and Mobile Computing
2015; 2(3): 33-36
Published online September 10, 2015 (http://www.aascit.org/journal/wcnmc)

American Association for Science and Technology



Erbium Doped Phase Matched Pulses Using Fiber Ring Laser Usable in Microwave Photonics Applications

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Citation
T. K. Subramaniam. Erbium Doped Phase Matched Pulses Using Fiber Ring Laser Usable in Microwave Photonics Applications. *International Journal of Wireless Communications, Networking and Mobile Computing*. Vol. 2, No. 3, 2015, pp. 33-36.

Keywords
Microwave Photonics,
Astronomy,
Electromagnetic Waves,
Dual-Wavelength Laser Source

Received: August 11, 2015
Revised: August 25, 2015
Accepted: August 26, 2015

Abstract
Microwave photonics is the practical application of electromagnetic waves with a wavelength between one millimeter and one meter. Microwaves are important for communications, and systems for detecting microwaves are crucial for astronomy. The term also includes high-frequency electronic systems. Using dual wavelength laser source and when these two wavelengths are separated at a desired frequency, microwave signals or mm-wave signals can be generated. These two wavelengths are generated from the same laser cavity for a better phase correlation. There is no need for a microwave reference source.

1. Introduction

There are four ways to generate low-phase-noise microwaves or mm-waves signal. They are, namely,

a) Microwave generation using external modulation)Optical injection locking, c)Optical Phase-Lock loop (OPLL) and d)Dual wavelength laser source. Using the first technique one can generate high quality microwave signals. If coherence is required between two optical waves then the OPLL technique is useful. For optical injection locking, a master laser and two slave lasers are used, so that an RF reference applied to the master laser undergoes frequency modulation and an optical carrier of different order of optical sidebands are generated at the output. The free running wavelengths of the two selected slave lasers are very close to the sidebands and are locked at the second order positive and negative values respectively, thus enabling optical injection locking technique Ref [1-4]. The technique used in this paper is the dual wavelength laser for microwave generation [Fig. 1].

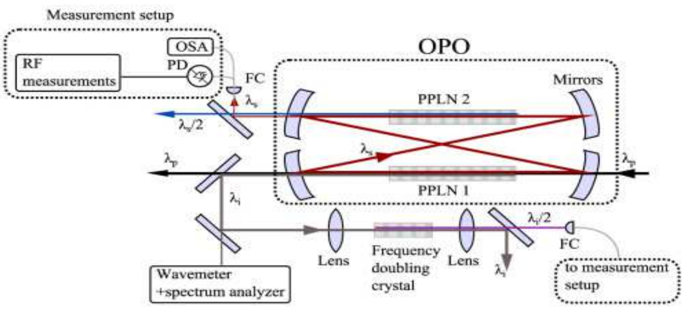

Figure 1. *Dual Wavelength Laser using FBG (Courtesy: Wikipedia).*

2. Methodology

The two wavelengths are separated by a desired frequency. They are not locked in phase. Lasing effect takes place from the same laser cavity and a reference microwave source is not necessary. Both wavelengths are used in a longitudinal mode. Two Fiber Bragg Gratings (FBG) are cascaded and an erbium doped fiber amplifier (EDFA) is used as a gain medium. Sometimes, it is better to use a semiconductor optical amplifier instead of an EDFA for reducing any mode competition between two laser wavelengths [Fig. 2]. The frequency difference between two incident laser beams should be equal to the frequency of the electrical beating signal at the output of the photodetector. Using optical heterodyne theory, the optical stability and the linewidth of the light sources dominate the phase noise, frequency purity and the stability of the generated microwave signal. Two phase-locked laser beams are thus needed and their phase noises should be reduced to the minimum level. The output power is divided into two parts in a ratio 9:1 with the help of an optical coupler. 90% of the optical power is fed into a photodetector and the remaining part of the optical power is sent to an optical spectrum analyzer (OSA) for the observation of a spectrum. Both wavelength lasers are single-longitudinal-mode lasers and the beating signal are verified by monitoring the output of the photodetector (PD) with a radio frequency (RF) electrical spectrum analyzer (ESA). The photodetector has a frequency response bandwidth of more than 10 GHz and the RF spectrum analyzer can scan the RF frequency up to 60 GHz Ref [5-9].

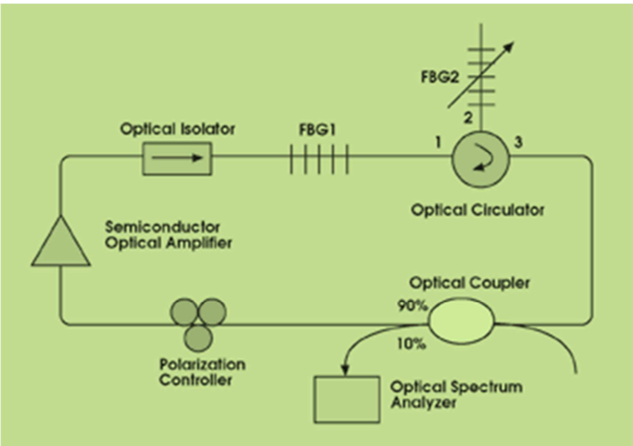

Figure 2. *Experimental set-up for FBG and SOA gain medium. (Courtesy: Wikipedia and M/s. Photonics Inc.).*

3. Working of the Various Devices Used

3.1. Fiber Bragg Grating

The primary application of fiber Bragg gratings is in optical communications systems. They are specifically used as notch filters. The two FBG's are designed to pass ultra-narrow transmission bands and fabricated based on equivalent phase shift (EPS) technique[Fig. 3].In signal processing, a band-stop filter or band-rejection filter is a filter that passes most frequencies unaltered, but attenuates those in a specific range to very low levels. It is the opposite of a band-pass filter. A notch filter is a band-stop filter with a narrow stop band (high Q factor). Optical multiplexer (mux) and demultiplexer (demux) are devices that select one of several analog or digital input signals and forwards the selected input into a single line. Multiplexers are mainly used to increase the amount of data that can be sent over the network within a certain amount of time and bandwidth. A multiplexer is also called a data selector. Demultiplexer is a device taking a single input signal and selecting one of many data-output-lines, which is connected to the single input. A multiplexer is often used with a complementary demultiplexer on the receiving end.)

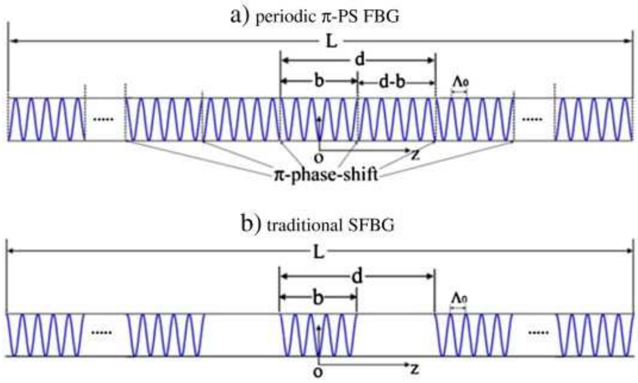

Figure 3. *Fiber Bragg Grating design for equal phase shift (EPS) (Courtesy: Wikipedia).*

3.2. Optical Circulator

It is a special fiber-optic component that can be used to separate optical signals that travel in opposite directions in an optical fiber analogous to the operation of an electronic circulator. An optical circulator is a three-port device designed such that light entering any port exits from the next. This means that if light enters port 1 it is emitted from port 2, but if some of the emitted light is reflected back to the circulator, it does not come out of port 1, but instead exits from port 3 [Fig. 4].

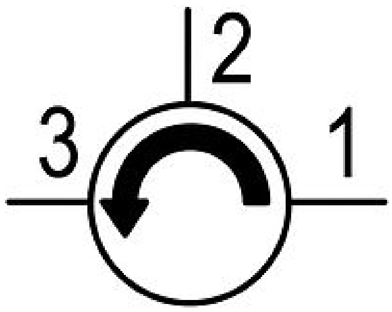

Figure 4. *An Optical Circulator. (Courtesy: Wikipedia).*

3.3. Optical Add-Drop Multiplexer (OADM)

An optical add-drop multiplexer (OADM) is a device used in wavelength division multiplexing systems for multiplexing and routing different channels of light into or out of a single mode fiber (SMF). This is a type of optical node, which is generally used for the construction of optical telecommunications networks. "Add" and "drop" here refer to the capability of the device to add one or more new wavelength channels to an existing multi-wavelength WDM signal, and/or to drop (remove) one or more channels, passing those signals to another network path [Fig. 5].

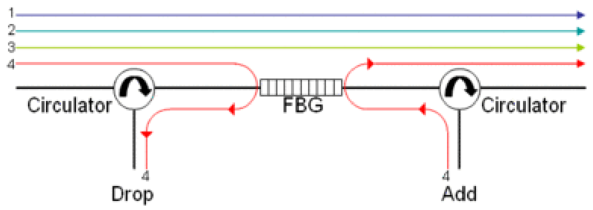

Figure 5. *Optical add-drop multiplexer (Courtesy: Wikipedia).*

4. Energy Levels and Mechanism of Excitation in Optical Fiber Laser

Energy Levels:

The Erbium doped silica fiber laser is a three-level laser. The energy level scheme for the optical pumping is shown below here [Fig 6].

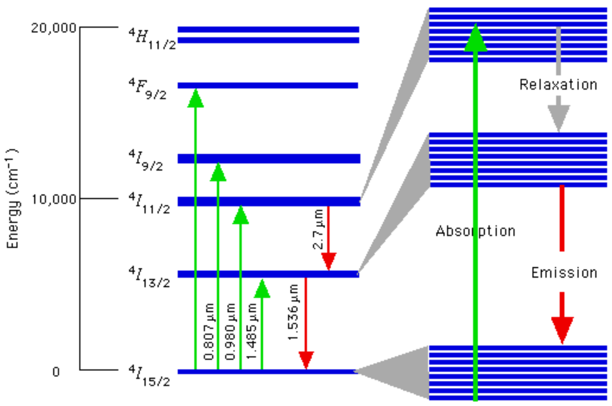

Figure 6. *Erbium Fiber Laser transitions. (Courtesy: Wikipedia).*

(The energy levels of Er^{3+} ion shows three absorption peaks at 0.807μm, 0.980μm and at 1.485μm. Here, on the Y-axis the energy is plotted in wave numbers and 1 cm^{-1} Ξ ν = 30GHz.)

In this scheme, optical pumping takes place from the ground state$^4I_{15/2}$ to the $^4I_{11/2}$ at a wavelength of λ= 0.98μm. Optical pumping can also occur from the lowest levels (ground state) to the upper laser state, $^4I_{13/2}$ at λ=1.485μm. Then rapid relaxation occurs to lowest sub-levels of $^4I_{13/2}$ from which 'laser action' is obtained in the region at λ=1.536μm and at λ= 2.7μm. The mechanism of 'population inversion' is strange in this level. The lower level of the fiber optic laser acts similar to a dye laser. Higher levels of this state are not populated to a significant extent and hence higher levels act as lower level of population inversion. Thus there will be a non-radiative decay of population into the lower levels of $^4I_{13/2}$ state.

Mechanism of lasing: The Erbium (Er^{3+}) is a rare-earth ion and has eleven electrons in the 4f orbital. It has a wide 'gain bandwidth' resulting from transition between the $^4I_{15/2}$ and the $^4I_{13/2}$ states. When this fiber is placed in a host medium all the (2J+1) components of the multiplets of this erbium ion are split and are homogeneously broadened due to neighboring oxygen ions in the silica glass. Hence all the sub-levels are further broadened due to inhomogeneous broadening, resulting in a wide "gain bandwidth" which is useful for the broadband optical communication application. The absorption cross-section of the levels, $^4I_{15/2} \rightarrow {}^4I_{11/2}$ (λ=1.485μm) and the levels $^4I_{15/2} \rightarrow {}^4I_{13/2}$ (λ=0.980 μm) give rise to two strong peaks. The $^4I_{15/2}$ level is split into sixteen sub-levels (2J+1, with J=15/2) and the $^4I_{13/2}$ level is split into fourteen sub-levels (2J+1, with J=13/2).Population inversion can be obtained through optical pumping using the λ=0.980μm, which lifts the electrons to the upper state $^4I_{11/2}$. An electron at this state has a 1μsec as lifetime and then it decays to the intermediate state $^4I_{11/2}$. The other intermediate state $^4I_{13/2}$ is a metastable state and has a lifetime of $t=10^{-3}$ seconds. Each decay results in spontaneous emission of a photon and so $t=t_{spontaneous}$. It may be noted here, that it is because of this long duration of 'spontaneous lifetime', lack of "Crosstalk" between communications channels have been made possible. Ref [10-13].Hence Erbium silica fiber is a three level laser and the laser emission uses the ground state as the lowest state. It should be noted that the erbium doped glass fiber laser must be pumped hard in order to achieve gain [Fig.7].

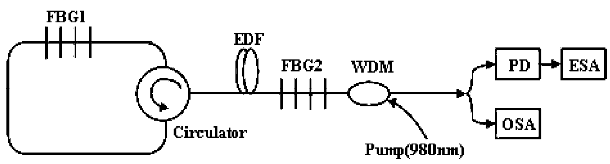

Figure 7. *EDFA pumped with FBG and Circulator. (Courtesy: Wikipedia).*

The output power of a single stage EDFA is shown below. [Fig 8].

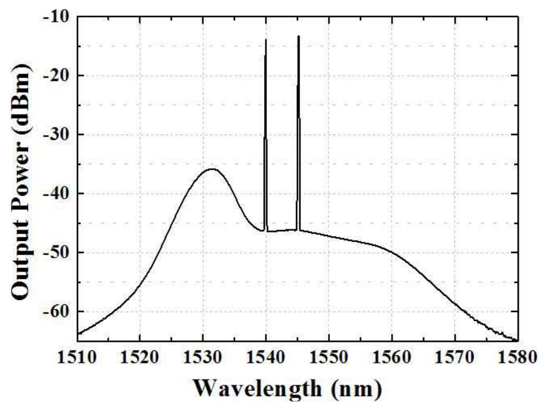

Figure 8. *Output power of a single stage EDFA (Courtesy: Wikipedia).*

Also, without a Fiber Bragg Grating (FBG), the erbium fiber can be used only as an inline optical amplifier in telecommunication networks. The following Table I below gives the properties of an Erbium-doped fiber used as an amplifier.

Table 1. *Properties of erbium fiber amplifiers (Courtesy: Oxford University Press).*

Properties of Amplifiers	Erbium doped fiber amplifiers
Active Medium	Er3+ ion in silica
Typical length	Few meters
Pumping	Optical
Gain Spectrum	Λ = 1500 to 1600nm
Gain Bandwidth	25 to 35 nm
Relaxation time	0.1 to 1 ms
Maximum Gain	30-50 dB
Saturation power	>10 dBm
Crosstalk	nil
Polarization	Insensitive
Noise figure	1-4 dB
Insertion loss	< 1dB
Optics	Pump laser diode couplers, fiber splice
Optoelectronic Integration	No

The free spectral response of a FBG is given below[Fig.9].

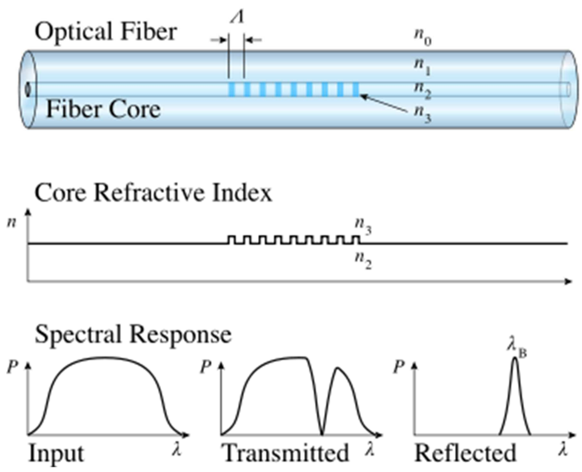

Figure 9. *Spectral response and refractive index profile of a FBG. (Courtesy: Wikipedia).*

5. Conclusion

A microwave signal can be generated, with a stability that is better than 2 MHz and a 5 dB bandwidth of less than 15 kHz at room temperature. The major application areas of microwave signal generation include broadband wireless access and sensor networks. Satellite communication systems, software-defined radio, and radar etc.

Acknowledgements

The author wishes to acknowledge the constant encouragement given to him by the management and by Prof. Dr. C. V. Jayakumar, Principal, Sri Sairam Engineering College, Chennai to publish research works in reputed international journals.

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