MILLIMETRE WAVE GENERATION BY FILTERING THE FM-IM SPECTRA OF A DIRECTLY MODULATED DFB LASER.

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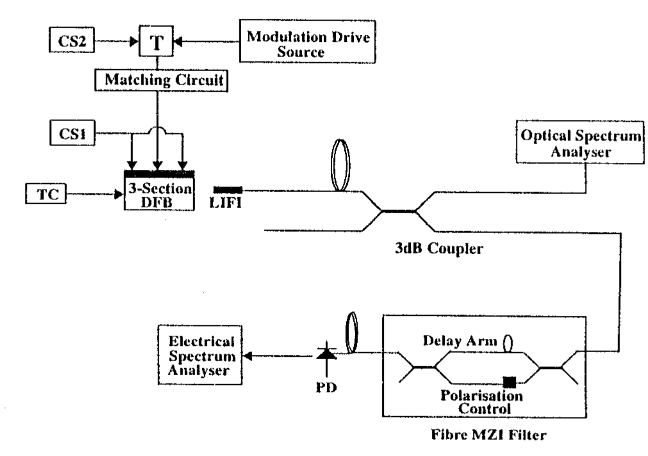
Abstract: The non-linear characteristics of semiconductor lasers have been exploited in order to generate low phase noise microwave and millimetre-wave frequencies for radio-over fibre applications. This is achieved using the modulation characteristics of a MQW-DFB semiconductor laser. A high FM index MQW-DFB laser is directly modulated at the resonant frequency of its FM characteristic response in order generate high order harmonics. By optimising the rf modulation frequency drive power, high order sideband components can be generated, selected and mixed on a photodetector to generate microwave and millimetre-wave frequencies. This paper presents results utilising the direct modulation technique, which demonstrate the generation of beat frequencies up to 25GHz. Optimization of the optical filtering process and of the phase-noise dependence of the generated beat frequency on the modulation drive source are also discussed.

Introduction: Exploitation of the millimetre-wave radio band is of great interest due to spectral congestion at lower radio frequency bands and its capacity for high data rate transmission of video and data services over a defined mobile/cellular radio network (for example: Mobile Broadband Services (MBS)) [1]. Optical fibre networks enable low cost efficient distribution of millimetre-wave frequencies to the cellular area of coverage. In principle two optical modes separated by the desired millimetre-wave frequency are generated and transmitted over the fibre network. The optical modes are then mixed on a photodetector of sufficient bandwidth in order to generate the required millimetre-wave signal. This signal is then radio transmitted within its designated coverage area known as a pico-cell (area of approximately 100 metre radius). Combining the optical fibre network and radio transmission has led to systems known as *Radio over Fibre* systems[2]. The application of radio-over-fibre systems has also been extended to optical injection locking of local oscillators in phased array antenna systems. Also microwave and millimetre-wave element feeds can be replaced with optical fibre feeds in order to reduce the mass and bulk, essential criteria in space based communication platforms.

This paper describes microwave and millimetre-wave frequency generation by frequency mixing the optically filtered directly modulated spectrum of a high FM index semiconductor Laser (MQW-DFB laser) on a high speed photo-detector. The generated beat frequency phase-noise dependence on the modulation drive source (frequency synthesizer) phase-noise is also discussed.

Experimental Principle: As illustrated in fig.1, a three contact MQW-DFB semiconductor laser is directly modulated in order to produce an IM/FM optical spectrum. The Multi Quantum Well structure of the laser device leads to a reduction in the active region volume and an increase in the differential gain coefficient[3]. These factors lead to an increased relaxation oscillation frequency and frequency chirp. The increased frequency chirp and higher relaxation oscillation frequency enable the generation of wideband FM spectra. The modulation frequency is selected to be at the resonant peak of the FM response characteristics, resulting in maximising the frequency deviation ($\Delta f/\Delta I$) of the laser device. The increased frequency deviation enables high FM modulation indices (B) to be achieved in order to optomise the optical spectrum. The FM index is selected to enhance the upper and lower order harmonics that are separated in frequency by the required beat signal frequency value.

Fig. 1



TC: Temperature Controller.
CS1: D.C Bias Current Supply To Outer Contacts of Laser.
CS2: D.C Bias Current Supply To Inner Contact of Laser.
T: 0.1-18GHz Bias T.
PD: InGaAs/InP High Speed Photodetector (Resp=0.85 A/W @1550nm; BW=20GHz).
LI FI: Laser Interface Fibre Isolator (60dB Isolation).

These components are selected using a Mach Zehnder interferometer (MZI) optical fibre filter in order to suppress unwanted harmonic components in the generated optical spectrum.

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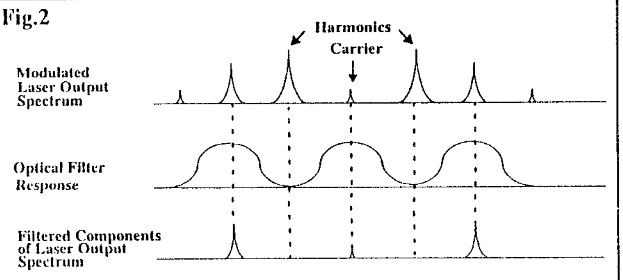
If the pure FM spectrum (neglecting the IM spectrum) of the laser was applied directly to the photodetector without filtering, no signal would be detected due to the amplitude and phase relation between the FM sideband components. The mixing of the FM sideband components cancel each other out. For this reason only the required sideband components are selected (filtered), suppressing all other components. The most suitable optical filter transmission characteristic is one with a rounded transmission peak, greater than 20dB suppression ratio and a free spectral range equal to the frequency separation of the selected optical components. Optical fibre filters incorporating multilayer dielectric coatings can be specifically designed for this purpose. However, in order to demostrate the principle of the experiment a Mach Zehnder optical filter was constructed. Although the sinusoidal response of the MZI filter offers poor suppression of unwanted harmonic components, it is adequate to ensure beat signal generation at the photodetector. The rounded response of the MZI transmission peaks offer low phase noise to intensity noise conversion[4]. The free spectral range of the MZI filter is chosen to be twice that of the modulation frequency in order to suppress unwanted adjacent optical harmonics to that of the desired optical components as illustrated in figure 2.

Fig.2



This filtering pattern also enables electronic stabilisation techniques to be employed in order to ensure that the laser wavelength remains locked to the peak of the filter pass band. In the experiment it was found that by housing the MZI in a polystyrene box the filter transmission peak remains relatively stable in relation to the laser wavelength. Once the desired harmonic components have been selected they are mixed on a high speed photodetector in order to generate the beat frequency.

In order to achieve high modulation indices the input impedance of the laser must be matched (50Ω) to the output impedance (50Ω) of the modulation source. The material structure and packaging of the semiconductor laser diode introduce inductive and capacitive parasitics which at high frequencies (3GHz) greatly reduce the amount of modulation signal absorbed by the actual laser diode (resistive element). For this reason narrowband microstrip impedance matching is used to match the low input impedance (a few Ohms) of the laser to that of the signal generator (modulation source) output. In the experiment a single stub matching circuit with a narrow band-pass region around 3GHz was designed.

Experimental Results: The two outer contacts of the laser were DC biased at 50mA (CS1) and the centre contact at 25.4mA (CS2). A modulation drive frequency of 3.111GHz at an output power of 4.6dBm was applied to the centre section of the laser. Figure 3 shows the optical spectrum under the mentioned drive conditions. The modulation index β=5.2 corresponds to an FM spectrum with amplitude enhanced fourth order harmonics. The upper and lower fourth order optical harmonics are filtered and mixed on the photo-detector. This generated a 24.87GHz beat signal as shown in figure 4. The beat signal linewidth is dependant on the linewidth of the modulation source. For this reason a synthesized narrow linewidth, stable frequency source must be used. The order of harmonic also effects the magnitude of the beat signal linewidth. Any phase pertubations in the modulation source signal is multiplied by the order of harmonic in the FM spectrum.

Fig. 3

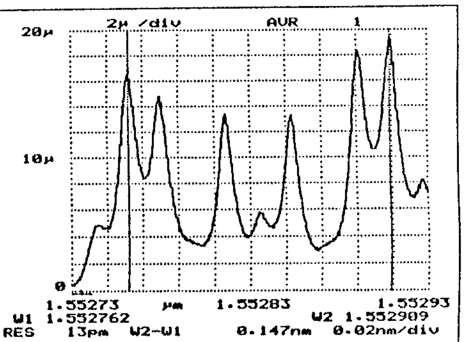
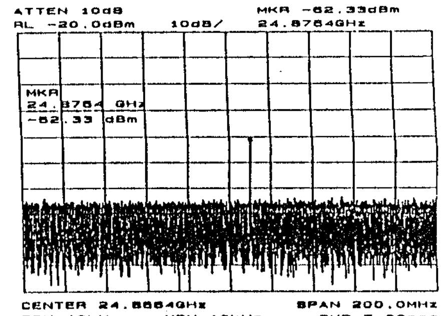


Fig. 4



Conclusion: This technique produces microwave and millimetre-waves without the need for optical phase noise reduction techniques. Frequencies up to 25GHz have been generated with the potential to generate higher frequencies by filtering higher order harmonics.

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