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FIBER RING BASED OPTICAL FREQUENCY COMB GENERATOR AND ITS APPLICATION

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ABSTRACT

A fiber ring based Optical Frequency Comb Generator is presented. Highly stable fiber laser combined with matched length cavity length correction loop gives stable output. The system is capable to generate a coherent optical comb of wider than 500 GHz, and with a relative flat spectral profile. Combined with the high frequency waveguide based photomixer, this system is capable to generate a high quality, tunable millimeter wave signal. The phase noise of the 110 GHz detected signal at 100 kHz offset is typically better than -82dBC/Hz, with a maximum power available from the photomixer directly equal to 0.18 mW. This presents a high quality, easily deliverable millimeter wave signal, and can be used in many millimeter/sub-millimeter applications such as the LO for phased array antenna or image system. The narrow linewidth and high stability of the signal generated from the photomixer will allow narrow band heterodyne detection, which significantly improves the signal to noise ratio of the detection scheme. The easily tuning in the frequency will benefit the accurate spectral scanning. Problems of the generation and delivery of the optical comb are also examined.

1. INTRODUCTION

High frequency and high quality signals are required in many applications, such as radio over fiber, or phased array antennas. Generating such a signal optically and delivering it through the low loss optical fiber is a desired approach. This approach takes the advantages of a centralized configuration, reduced cost in maintenance, wideband capability and extremely low loss distribution.

Traditional methods of generation of modulated optical signal limit the maximum of the frequency to be delivered by the fiber to around 40GHz. These limitations were not only caused by the effective response of photodetector, but also by the methods of producing high quality sources carried by the optical signal. Current developments of high-speed, high-

power photomixer modules [1, 2] make the delivery of high frequency and moderate power signals more feasible. As the demand for high frequency signal distribution network grows, the development of a high quality millimeter wave photonic generator is needed. The requirement of a system that not only is capable of generating a highly stable millimeter-wave signal, but also provides adequate bandwidth coverage and tunability, poses a major challenge in its development.

The Optical frequency comb generator (OFCG) has been widely used as an optical frequency chain [3] in the precision measurement of the optical frequency schemes, as it allows the direct measurement of wide optical frequency intervals. The OFCG generates an optical spectrum consisting of a series of optical comb lines which are coherent with each other. These lines are equally separated by a microwave reference frequency. Hence phase locking or injection locking lasers to these comb lines will result in the lasers being locked to each other.

The most straightforward method of generating an optical comb is to modulate a laser beam by a microwave signal through an electro-optic modulator. However, the spectrum produced is limited to within a small frequency range. Furthermore, the sidebands generated do not have regular profile. Some of the sidebands may go missing or have low amplitude, which is not desired for an optical comb. A resonant electro-optic modulator type optical frequency comb generator relies on placing the optical modulator inside an optical resonator to enhance the modulation. The modulation frequency must coincide with one of the resonance frequencies of the cavity. This type of comb generator was first demonstrated by Kobayashi et al in 1972 [4].

Fiber ring based optical comb generator [5,6,7] has the advantage of utilizing low cost telecommunication components. The fiber based long cavity provides the

potential of both being compact and having the ability to tune in small frequency steps. The latter is often limited by an order of few GHz in other resonant types of OFCG, since the minimum tuning step is limited by the length of the resonance cavity.

In this paper we present a fiber ring based optical frequency comb generator which is capable of stable single mode operation.

2. FIBER RING BASED OPTICAL FREQUENCY COMB GENERATOR

The fiber ring based OFCG consists mainly of an optical amplifier, an optical phase modulator, fiber delay lines and a 3dB coupler, as shown in Figure 1. Two isolators are used to ensure that the light propagates only in one direction, and to avoid unwanted reflections. The phase modulator is polarisation dependent and so a polarisation controller is required before the phase modulator. Input and output for the comb generator is via a 3 dB coupler. With the optical delay line in the cavity, the cavity length of the OFCG can be controlled so that the free spectral range of the cavity is nearly equal to 5 MHz.

The optical amplifier compensates the loss within the cavity. The round-trip transmittance of the loop is kept at a value that close to but still lower than unity, and hence the high finesse of the cavity is maintained. This

allows inserting many optical components within the loop. Furthermore, the resonance of the cavity no longer only depends on the coupling ratio of the coupler used in the loop. This helps to improve the efficiency of the power that can be coupled into and out of the loop.

A highly stable fiber laser is used as the master laser. This fiber laser has a linewidth of 2-3 kHz, and its frequency is said to be stable over time. However, few MHz of low frequency drift ($< 1\text{Hz}$) is still expected, which is common for the laser without stabilizing to a reference. The use of a narrow linewidth laser as the reference ensures that the OFCG will be operating in a single mode condition. Each of the comb line in this case will only contain one single cavity mode.

The long cavity does pick up more acoustic noise than shorter cavities. Furthermore, the thermal slope of the ring cavity is measured at the order of 22ppm/Deg C. The dense spaced cavity modes suffer frequency drift due to the noise or thermal changes. As a result, the relative drift of the frequency of the reference laser and the cavity mode are significant enough to destroy the stable operation of the OFCG. This is worsened by the frequency drift of the master laser itself. Under laboratory condition, the OFCG can not maintain stable operation unless it is enclosed within a box. Even when measures of isolation are taken, the period of the stable operation will only last a few seconds before it drift into mode hopping.

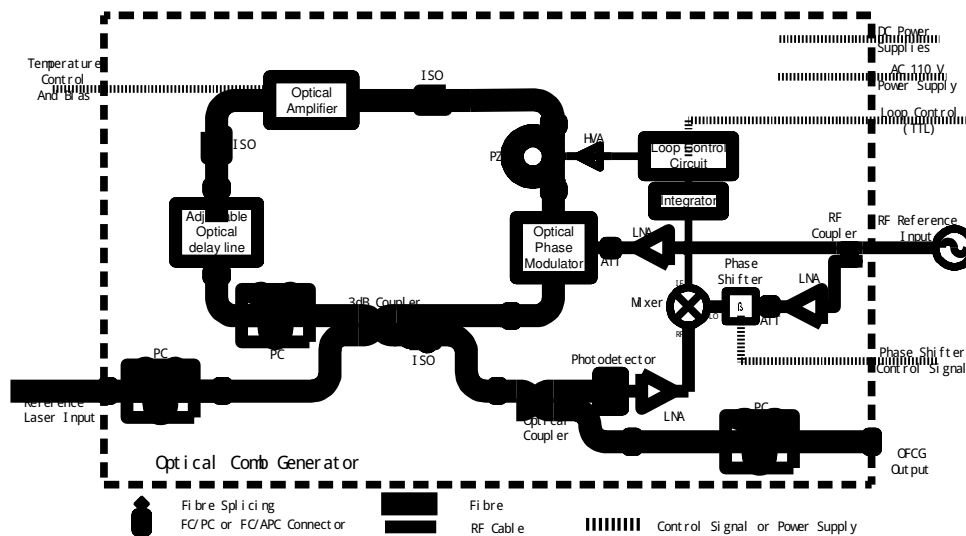


Figure 1 Set up of the OFCG

ISO: Optical isolator, PC: Polarization Controller, HVA: High Voltage Amplifier

To obtain stable operation, a loop length servo loop therefore has to be used to keep one of the cavity modes coincident with the reference laser frequency. This was done by detecting the loop length error signal and then feeding it back into the cavity by a fiber stretcher.

3. MILLIMETER WAVE GENERATION FROM THE OFCG

By using the narrow linewidth laser as the reference and employing the loop length control, the performance of the comb generator is greatly improved. Stable operation in the same condition can be achieved well exceeding half an hour, and can be further improved if active temperature stabilization of the unit is adopted.

The locking bandwidth of the OFCG is measured to be at the order of 50 kHz. That means the modulation frequency can be continuously tuned by 50 kHz without lost of the comb. The profile of the comb can change slightly, especially at the edges of the comb. However, this is not our first concern, for the power of the comb lines within the usable band is still enough to lock the lasers.

automatically. Step tunings can be realized within one second.

Figure 2 shows a typical comb spectrum generated by this OFCG. The RF power we used is only 12 dBm, and the power of the reference laser 0 dBm. Frequency spacing between the comb lines can be set between 8 to 12.5 GHz at 5MHz grid.

The average power of the OFCG output can reach 0 dBm, with all the comb lines having a power level of better than -30 dBm. The span of the comb profile can be reach 5 nm within a 10 dB power envelop. With reduced cavity length, the comb span can be much wider.

A millimeter wave signal produced by beating the comb directly is shown in Figure 3. For a 90 GHz signal, which is 10 times the modulation frequency, a signal to noise ratio of better than 90 dBc/Hz at 100 kHz offset can be achieved. By locking a slave laser to the comb lines, millimeter wave signals up to 157 GHz has been generated, limited by the response of the photodetector. The optical phase locked loop employed inferiors the signal to noise ratio to -82dBc/Hz at 100 kHz offset.

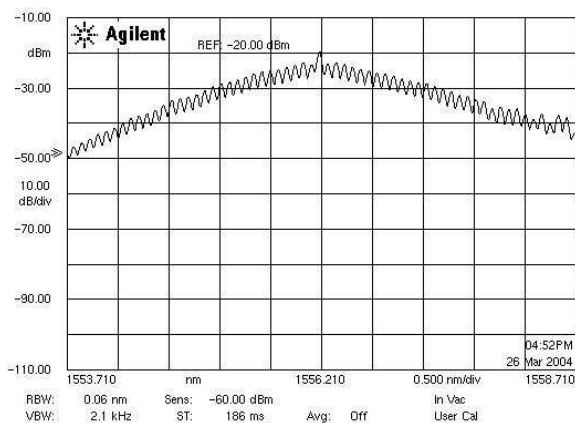


Figure 2 Typical optical comb spectrum produced by the fiber ring based OFCG

Further tuning can be achieved by changing the length of the cavity. However, it proves to be difficult to make large changes. Alternatively, due to the long cavity of the OFCG, coarse tunings can be made at 5MHz. There is no worrying that the reference laser frequency will fall in between the adjacent cavity modes, as the active length control can capture the reference laser frequency

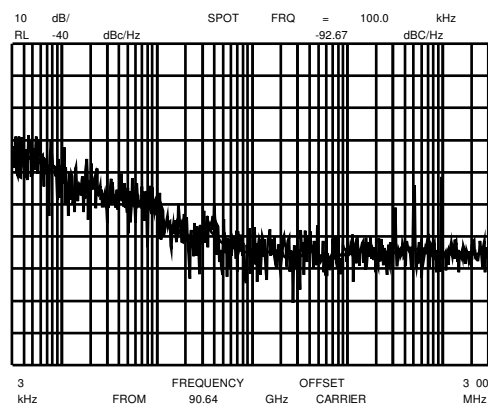
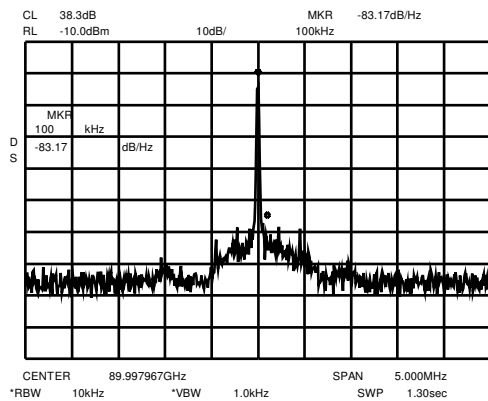


Figure 3 90 GHz signal produced by self-beat of the OFCG output and its phase noise

4. TRANSMITTING THE SIGNAL

Although highly stable millimeter wave signals can be generated optically, transmitting the millimeter wave signal through an optical fiber without losing its stability is not an easy task. The acoustic noise and thermal drift will certainly add jitter to the signal itself. Due to the short wavelength of the millimeter wave signal, active length control must be employed, such as those in [1].

The polarization mode dispersion (PMD) of the delivery fiber is also a factor that influences the quality and efficiency of the delivered signal. The efficiency of the millimeter wave generation relies on the polarization alignment of the two wavelengths. Although inside the generator, the state of polarization (SOP) alignment of the two lasers can be made nearly perfect, the transmission through the fiber will disperse the SOPs. It is concluded that the local differential

group delay of the fiber should be less than a quarter of the period of the delivered signal to avoid the efficiency degrading by 3dB.

5. CONCLUSION

In this paper we had presented a fiber ring based optical comb generator which is capable of stable, single mode operation. The spectrum of the comb can cover as wide as 5 nm, and the comb spacing can be tuned with 5 MHz steps within the range from 8 GHz to 12.5 GHz.

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