FIBER RING BASED OPTICAL FREQUENCY COMB GENERATOR WITH COMB LINE SPACING TUNABILTY

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ABSTRACT

A fiber ring based Optical Frequency Comb Generator with tunability in comb line spacing, fast tuning of 10 MHz per step with speed much better than 0.1 s, and a high coherence is demonstrated.

1. INTRODUCTION

Optical frequency reference sources with coherent phase relationships are desired in many applications such as high purity millimeter wave generation, radio over fiber communications, phased array antennas, stabilized wavelength division multiplexing techniques and optical signal processing. The optical frequency comb generator (OFCG) is known to produce such coherent comb lines over a wide spectral range with fixed frequency spacing [1,2].

For many applications, an optical comb with a predictable, flat and regular comb profile, and with each of the comb lines in the spectral range of interest having moderate optical power, is required. Furthermore, flexibility in fine and coarse tuning of the optical comb spacing is also important. Fiber ring based OFCGs [3,4,5] can offer both features at the same time; they also utilize low cost telecommunication components which are easily coupled in fiber. In this paper we present such a fiber ring based OFCG which is capable of locking to narrow linewidth reference light sources, and of operating in a stable single mode. An improvement in the configuration also benefits the system by generating a stable central comb line.

2. FIBER RING BASED OFCG CONFIGURATION

The fiber ring based OFCG was first proposed by Ho and Kahn [3]. Theoretical analysis also illustrated the principle of operation and the spectrum of the optical comb was shown. Pioneering work was carried out by Seeds' group at UCL, who successfully demonstrated a THz comb span from a fiber ring based OFCG [4].

The operation of the fiber ring based OFCG is based on using a resonant cavity to enhance the phase modulation of the light to help spread the sideband spectrum widely. Due to the multiple passes through the electro-optical modulator (EOM), pulse trains are formed within the cavity and an optical comb is produced as a result. Due to its exceptionally long cavity compared to other types of OFCG, matching the cavity length such that its resonances coincide with both the reference lightwave frequency and the RF reference presents a major challenge. Without this matching, the comb generation will be neither efficient nor stable. The UCL group has adopted a wide linewidth laser source, operating the OFCG in multiple cavity modes to help stabilize the comb; thus, each of the comb lines is composed of several cavity modes. The alternative approach is actively tracking the reference laser frequency drift by adjusting the cavity length [5], keeping the comb in stable single mode operation.

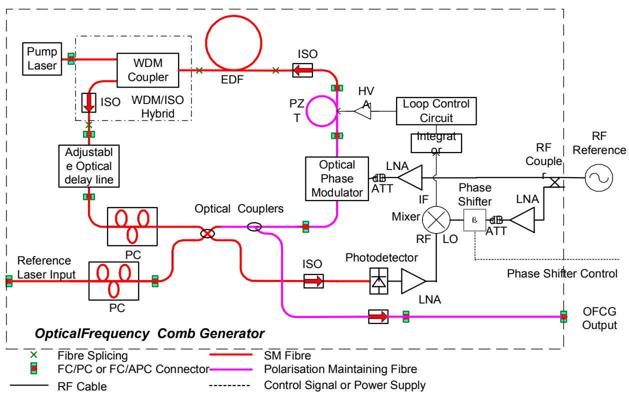

Figure 1. Dual coupler configuration OFCG with a fiber stretcher to stabilize the comb.
HVA: High Voltage Amplifier; ISO: Optical Isolator; PZT: Piezoelectric fiber stretcher; PC: Polarization Controller; EDF: Erbium Doped Fiber; LNA: Low Noise Amplifier

Our fiber ring based OFCG that consists of an optical amplifier, an optical phase modulator, fiber delay lines and optical couplers, as shown in Figure 1. Isolators are used to ensure that the light propagates only in one direction, and to avoid unwanted reflections. The phase modulator is polarization dependent and packaged with PM fiber, so a polarization controller is required before it. An additional polarizer can be used to suppress the unwanted polarization and to ensure that the output comb has a stable polarization. With the optical delay line in the cavity, the cavity length of the OFCG can be adjusted and controlled so that the free spectral rang of the cavity is almost equal to 5 MHz. A fast fiber stretcher allows fast, accurate adjusting of the cavity length and is controlled by the cavity length servo loop, discussed later. All these optical components are placed within an enclosed box to isolate them from ambient acoustic noise and thermal drift.

A cavity length servo loop is used to hold one of the cavity modes coincident with the reference laser frequency. This is done by servoing the amplitude of the 1^{st} harmonic beat signal to a constant value. A homodyne detection method is used to measure the amplitude of the 1^{st} sideband beat signal. Due to the high thermal sensitivity of the ring cavity, this part is kept in a separate box from the remaining optical components. A stable narrow linewidth fiber laser is used as the reference light. A dual coupler configuration is adopted in our design to avoid the destructive interference between the reference lightwave and the central line of the comb. Analysis shows that the output comb is then a copy of the lightwave circulating inside the cavity, and the central comb line is always maintained at a certain power level, higher than the rest of the comb lines, and is less sensitive to the modulation depth, cavity gain and optical power level.

3. PERFORMANCE OF THE OFCG

Due to the optical amplifier inside the cavity, there is no requirement for a high power reference laser. The long ring cavity does pick up more acoustic noise than shorter cavities, and presents a tighter requirement for the stability of the reference laser frequency drift. Without the tracking loop closed, the OFCG cannot work stably. However, when the loop is closed, the ring length is automatically adjusted to adapt to the wavelength of the reference laser, and to track its drift.

The long cavity of the OFCG also makes possible the fast switching of the comb line spacing by the RF reference frequency, in steps of the free spectral range. Due to the electrical limits of the cavity length servo loop, our comb generator will allow the RF modulation frequency (comb line spacing) to operate from 8 GHz to 12.5 GHz. By balancing the appropriate path lengths,, the phase relationship between the beat signal and the LO signal in the homodyne detection part can be maintained roughly matched over a wide frequency range for good detection efficiency. In this case, there is no need to adjust the phase shifter to achieve phase matching. Our models show that the build up time of the comb in the OFCG is typically less than 1 ms; the fiber stretcher will then maintain its position during the frequency switching, and hence the cavity length. Therefore, both resonance conditions will still hold to maintain the stable operation of the OFCG. The result is that the OFCG can be fast tuned with a frequency step of 5 MHz in less than 0.1s, which is limited by the updating speed of the optical spectrum analyzer. Experimental results also confirm a stronger central comb line with the dual coupler configuration.

Fine tuning with the range of 10 kHz to 5 MHz needs the ring cavity length to be adjusted. This is limited by the speed and accuracy of the optical delay line. Combined with the fast coarse tuning at 5 MHz steps, it has been possible to construct an OFCG to cover the whole operational frequency range.

4. CONCLUSION

In this paper we have presented a fiber ring based optical comb generator which is capable of stable, single mode operation, and also of providing adequate tunability in the comb line spacing.

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