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Design of Electro-optic Oscillator using Semiconductor Laser for generation of Optical Millimeter & Microwave Signals

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***Abstract*— Communication systems in future will require data rates on the order of 10Gbps or more. Hence the millimetre wave photonic systems will be a good approach for such high speed communication systems. The Millimeter wave and Microwave region communication systems on the other had suffers an major drawback of not having a good quality of carrier signals. The various electrical oscillators available today produce an continuous wave with low phase noise at frequencies in Megahertz range. Microwave signals can be generated by using Impact diode and Gunn diode oscillators but they generate frequencies upto 300GHz only moreover due to avalanche breakdown required for signal generation the noise performance is very poor. Option left is an electro-optic method of millimeter and microwave generation. In this paper a design study of one configuration of electro Optic Oscillator is done.**

***Index Terms*— Electro-optic oscillator, Mach-Zehnder Modulator, Phase Noise, PIN Photodiode.**

I. INTRODUCTION

Photonic generation of the Microwaves and Millimeter Waves can be done in several ways. For example by beating two laser beams, modulating a laser beam, optical tuning of microwave oscillators, optical injection locking of a microwave oscillator or by using an Electrooptic Oscillator. In this paper generation of the millimeter and microwaves waves is proposed by using the electrooptic oscillator.

The application of the fiber resonator in the optical generation of microwave signals is presented. Here the beam of a laser is modulated by a Mach Zehnder optical modulator. By applying a microwave bandpass filter and coupler microwave oscillation is generated. The performance can be further improved by applying a fiber resonator in the feedback loop. The high Q factor of the fiber resonator stabilizes the generated frequency. With proper design the phase noise can he reduced to an extremely low level. The generated microwave signal can be obtained either in the electrical domain or in the optical domain.

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II. SYSTEM OVERVI EW

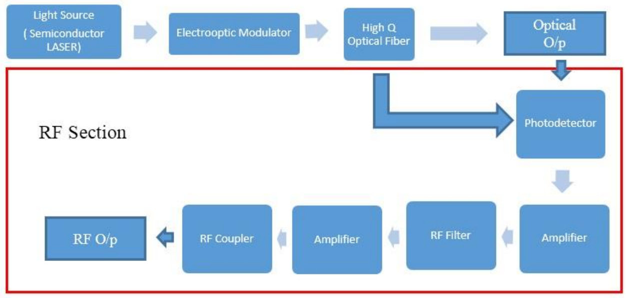


Fig 1. Block Diagram of the system

The continuous light energy coming from a laser is converted to microwave signal. Light from the laser goes through a modulator. The modulation microwave signal comes from the output of the microwave amplifier after crossing a -10dB directional coupler. Resonant element can be an optic fiber equivalent to a delay line. It can also be an optical mini-resonator coupled to the optical fiber at the output of the phase modulator. The microwave signal is amplified after the photodiode. Electrooptic oscillator can have optic output with the modulated optical signal and microwave output through a directional coupler[1]. The oscillator consists of an amplifier of gain G and a feedback transfer function in a closed loop. The gain G compensates for the losses, while feedback transfer function selects the oscillation frequency. Purity of microwave signal is achieved because of the delay line inserted into the loop. For example, a 4 km delay corresponds to 20 µsec time for optical energy to stay in the line. It is equivalent to a quality factor $Q=2\pi FT$ where F is the microwave frequency and T the delay induced by the delay line.

The electrooptic oscillator is able to generate high purity low phase noise microwave and optical signal. The application covers a wide area of photonic and RF systems such as microwave frequency standards, radars, RF photonics and optical signal processing . An electrooptic oscillator is similar to that of the Barkhausen's oscillator. In the Barkhausen's oscillator, the flux of electrons from the cathode to the anode is controlled by the potential on the inverting grid and thus this potential is affected by the feedback current in the anode circuit comprising a resonant network. The function of the grid is replaced by an electrical-optical converter, the function of the anode by an optical-electrical converter, and finally the energy-storage function of the LC circuit by a long optical delay line. Namely, the oscillator converts the continuous light energy to an radio frequency signal. The electrooptic oscillator with dynamic filter is capable of tracking the instantaneous frequency of a frequency modulated signal. Theoretical analysis coupled with experimental findings are presented and they are in good agreement.

The optical technology offers a new method for constructing extremely low noise microwave oscillators. The reason is that utilizing an optical cavity as a microwave resonator an extremely high Q factor can be achieved. For that purpose a long fiber with high reflectance on its both ends is the best approach. The Q factor of that resonator is:

$$Q = \pi k \frac{\exp(-\alpha_r d/2)}{1 - \exp(-\alpha_r d)}$$

where

$$\alpha_r = \alpha_f + \frac{1}{2d} \ln [1/(R_1 R_2)]$$

Where,

α_f = intensity attenuation factor of the fiber
RI ,R2= reflectance at the ends of thefiber
d = length of the fiber
k = number of half wavelengths along the fiber:

As seen Q/k is strongly dependent on the reflectance. High Q/k is only obtained if the reflectance are very close to unity. The reflectance are determined by the mirrors at the fiber ends and by the coupling in and out of the fiber resonator. As the fiber becomes longer more resonances will occur and they will he closer to each other, or by other words the frequency difference between them will he smaller. Therefore keeping the operation of a system at a specific resonant frequency becomes more difficult. increasing the length of the fiber, k the number of the half wavelengths along the fiber will also he increased resulting in a proportional increase in the Q factor. This way an extraordinary enhancement of the Q factor is achieved. However, the number of resonance will also be increased and that makes the separation of the resonance more difficult.

III. SYSTEM BLOCKS

A. Continuous Wave LASER

A continuous wave laser generates continuous wave optical signal which is having an frequency of 193.Thz. The linewidth of the laser used is set to 10 MHz and the initial phase shift is 0 degree. In the CW laser the average output power is specified. The laser phase noise is modelled by using the probability density function:

$$f(\Delta\varphi) = \frac{1}{2\pi\sqrt{\Delta f dt}} \cdot e^{-\frac{\Delta\varphi^2}{4\pi\Delta f dt}}$$

Where Δφ is the phase difference between two successive time instants and dt is the time discretization.

A Gaussian random variable for the phase difference between two successive time instants with zero mean and a variance equal to 2π√Δf has been assumed with Δf as the laser linewidth.

B. Electrooptic Modulator

The electrooptic modulator used is an Mach-Zehnder modulator. It is an intensity modulator based on an interferometric principle. It consists of two 3dB couplers which are connected by two waveguides of equal length.

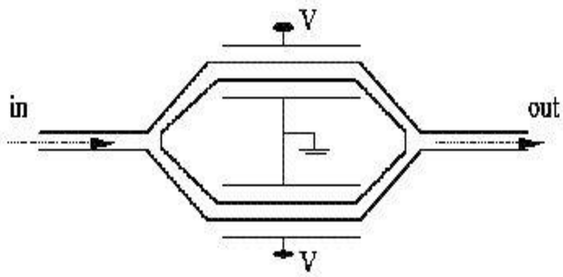


Fig 2. Construction of an Mach-Zehnder Modulator

By means of an electrooptic effect an externally applied voltage can be used to vary the refractive index in the waveguide branches. The different paths can lead to constructive and destructive interference at the output depending on the applied voltage. The equations that describe the behavior of the Mach-Zehnder modulator are:

$$E_{out}(t) = E_{in}(t) \cdot \cos(\Delta\theta(t)) \cdot \exp(j \cdot \Delta\phi(t))$$

where Δθ is the phsase difference between the two branches and Δϕ is the signal phase change.

C. Fiber Optic Delay Line

Single-mode optical fiber is an attractive delay medium for processing microwave frequency signals due to its extremely low loss (<0.1 dB/ps) and large available time-bandwidth product (in excess of 10^5). Single-mode optical fiber is capable of accurately transmitting modulated signals with bandwidths exceeding 100 GHz over a l-km distance with losses less than 0.5 dB [4]. Since only one mode is guided, its phase and polarization (a superposition of two polarization modes) can be determined at any point along the length of the fiber. As a result, single-mode fibers can be used as flexible optical paths in interferometers that sense environmental effects which perturb the fiber and thus the relative phase of the guided light. With a 4 km optical delay line in the electrooptic oscillator a 10GHz oscillator prototype exhibits a frequency flicker of 3.7×10^{-12} and a phase noise lower than -140dB rad^2/Hz at 10 KHz off the carrier[4]. Also the 4Km delay corresponds to 20μsec time for optical energy to stay in the line.

D. Photodiode

In our system PIN photodiode is used. The PIN photodiode diode converts an optical signal into an electrical current based on the device's responsivity. Its responsivity is 1A/W , dark current is set to 10 nA and center frequency is 193.1Thz. The frequency response of PIN photodiode is modelled as follows :

$$\frac{I_{out}}{i_{in}} = \frac{1}{1 + RC \cdot s}$$

Where, R is the load resistance and C is the junction capacitance. The sensitivity of a PIN photodiode can be defined in terms of its noise equivalent power which defines the point where the received power results in an SNR=1.

E. Amplifier

The gain of the amplifier used is 10 dB. Noise power is set to -60 dBm. Gain of the amplifier is defined as :

$$\frac{P_{out}}{P_{in}} = 10^{Gain/10}$$

Where gain is specified in dB.

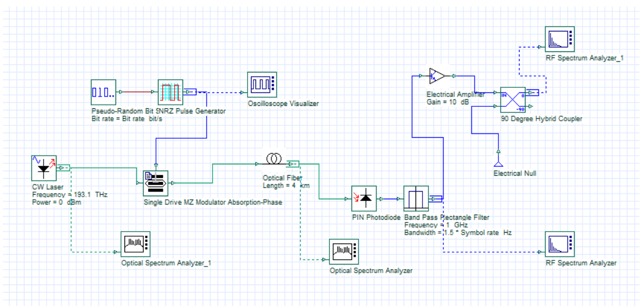
F. RF Filter

A filter is a two port network used to control the frequency response at a certain point in a system by providing transmission within the passband of the filter and attenuation in the stopband of the filter. The filter used is an Band Pass Filter of rectangle frequency transfer function. Its frequency is set to 10GHz and the bandwidth is 1.5×Symbol rate in Hz. Insertion loss is 0dB.

G. RF Coupler

Couplers are devices in which two transmission lines pass close enough to each other for energy propagating on one line to couple to the other line. A 3dB 90° or 180° hybrid splits an input signal into two equal amplitude outputs. A directional coupler normally splits an input signal into two unequal amplitude outputs. The coupler allows user to define gain and phase balance. Various applications of couplers are mixers, power combiners, modulators,etc. The 90° coupler is used for combining the electrical signals.

IV. Circuit Diagram



Fia 2. An Electro-optic Oscillator using Semiconductor Laser for generation of Optical Microwave Signal

V. Circuit Components

- The Continuous Wave Laser used is having a frequency of 193.1THz, linewidth of 10MHz and a phase shift of 0 Degree.
- The Mach-Zehnder Modulator is having an extinction ratio of 30dB with no frequency chirp.
- The fiber optic delay line has the reference wavelength of 1550nm and attenuation of 0.2 dB/Km and an dispersion of 16.75ps/nm/km.
- Photodiode is having an center frequency of 193.1THz, dark current of 10nA and responsivity of 1A/W.
- The filter is an Band Pass Filter of rectangle frequency transfer function with frequency set to 10GHz , bandwidth 1.5×Symbol rate in Hz and Insertion loss of 0dB.
- The 90° coupler is used for combining the electrical signals.

VI. Conclusion

Hence we are theoretically and experimentally studying the performance of a single-loop OEO using dynamic filter in place of a conventional RF filter. Theoretical analyses coupled with experimental findings are in good agreement.

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