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Conservation of AM index of a rf subcarrier in IM–DD optical link

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ABSTRACT

This paper presents experimental observations on amplitude modulation (AM) index conservation of an amplitude modulated (AM) rf subcarrier which produces direct intensity modulation (IM) of a laser diode (LD) lasing at 1557.1 nm and subsequently detected in a InGaAs photodiode (PD). The AM index of the input subcarrier is identical with that of the detected subcarrier at the output of the photodiode. This confirms the linearity of the direct modulation process as well as the linearity of the responsivity curve of the photodiode.

1. Introduction

With the advent of semiconductor lasers in 1962 and its operation over the visible and near infrared (IR) part of the electromagnetic spectrum, a new era in communication has started. Light has a ultrawide bandwidth ~THz and optical fiber has also a bandwidth of ~50 THz around 1550 nm wavelength region with the minimum of fiber loss which stands at 0.2 dB/km.

Hence, light has enormous capacity of carrying information be in the form of audio, video and data. The most common form of optical modulation is the intensity modulation and the simplest form of its detection is direct detection in a photodiode. It is often called as IM–DD [1–7] communication. Significant amount of research work [1–17] has been carried out on direct modulation. In direct modulation, the bias current of the LD is modulated. Since the optical bandwidth is very large, use of rf/microwave subcarrier intensity modulation of the lightwave is very much efficient for transmitting huge amount of information. The subcarrier can be pre-modulated in amplitude, frequency or phase. Simultaneous optical intensity modulation of the same optical carrier by a group of large number of subcarriers is, however, limited by intermodulation distortion (IMD). Keeping the modulation depths of individual subcarriers low, the IMD level can be kept under control.

In this paper, we investigate sinusoidal subcarrier intensity modulation (IM) of a laser diode lasing at 1557.1 nm where the rf subcarrier is pre-amplitude modulated by a sinusoidal audio frequency signal. This lightwave, intensity modulated by a pre-modulated rf subcarrier, is detected in a InGaAs photodiode (PD). The detected signal is the rf subcarrier which is amplitude modulated. The AM index of the detected subcarrier has been found to be the same as that of the input subcarrier producing intensity modulation of the lightwave. This is an important result which indicates perfect linearity of the direct modulation process.

2. Theory

The output optical power of the LD as a function of LD bias current is shown in Fig. 1.

The curve is fairly linear above the threshold bias current, I_{th} = 41.6 mA. The slope of the linear portion of the *L*–*I* curve is 0.117 mW/mA. The InGaAs photodiode has a responsivity curve which is shown in Fig. 2.

The PD response is fairly linear up to input optical power level of 8.5 mW. The responsivity as calculated from the slope of the response is 0.88 mA/mW at the operating wavelength of 1557.1 nm.

The low frequency rf response of the LD up to 3 MHz modulation frequency is perfectly constant since the LD has usually modulation bandwidth of a few GHz. The intensity modulating signal is sinusoidal in nature which is detected in the InGaAs PD and its amplitude is plotted with modulating signal frequency to yield

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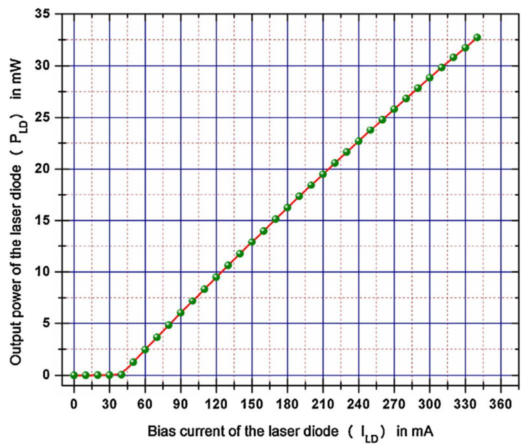

Fig. 1. Optical output power variation with LD bias current.

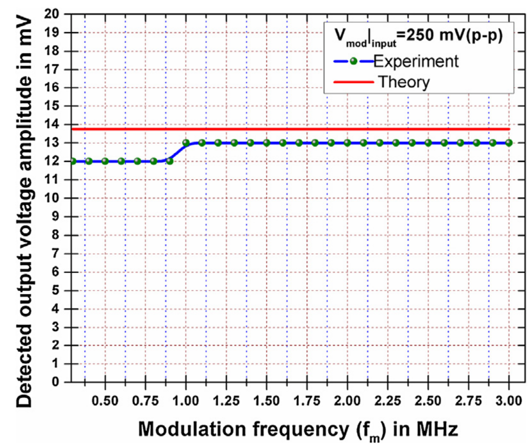

Fig. 3. Modulation frequency response of the laser diode for IM index = 6%. Modulation signal is applied to the LD mount through a bias tee.

the frequency response. The output optical power (P_0) of the LD is related with the bias current as

$$P_0 \propto (I - I_{th}) = k(I - I_{th}) \tag{1}$$

where k = proportionality constant. To calculate the IM index of the LD we write Eq. (1) as

$$\ln P_0 = \ln k + \ln (I - I_{th})$$

$$\therefore \quad \frac{\delta P_0}{P_0} = \frac{\delta I}{I - I_{th}} \tag{2}$$

In presence of sinusoidal IM, we can write

$$P_0(t) = P_0(1 + m(t)) \tag{3}$$

where $m(t)$ is the optical power modulation.

Then, from Eq. (3)

$$\frac{P(t) - P_0}{P_0} = m(t) \tag{4}$$

$$\therefore \quad m(t) = \frac{\delta P_0(t)}{P_0} \tag{5}$$

Using Eqs. (2) and (5), we get an expression for IM index as

$$m = \frac{\Delta I}{I - I_{th}} \tag{6}$$

In experiment, we have used modulating signal voltage amplitudes (V_m) of 125 mV and 250 mV. This voltage appears across the 50 Ω input impedance of the LD. This voltage produces a change in LD bias current (ΔI) of $V_m/50\,\Omega$ which is calculated to be $\Delta I = 125/50 = 2.5$ mA and $250/50 = 5$ mA respectively. Taking, $I_{th} = 41.6$ mA and $I = 2I_{th}$, the calculated IM indices using Eq. (6) are given by $m_1 = 2.5/41.6 = 6\%$ and $m_2 = 5/41.6 = 12\%$ respectively.

Now, the PD output signal voltage is calculated as

$$V_0 = \eta P_{LD} R_L m \tag{7}$$

where η is the responsivity of PD, P_{LD} is the LD output power fed to the input of the PD, $R_L = 50\,\Omega$ is the load resistance and m is the IM index. Putting $\eta = 0.88$ mA/mW, $P_{LD} = 5.21$ mW, $m_1 = 0.06$ and $m_2 = 0.12$, we get the output voltages of the PD as $V_{o1} = 13.75$ mV and $V_{o2} = 27.5$ mV.

These values fit well with experimental data within the limits of experimental error. This is shown in Figs. 3 and 4.

3. Pre-modulated rf subcarrier direct modulation

A schematic diagram of the circuit for the measurement of input and output subcarrier AM indices is shown in Fig. 5.

The laser diode (LD) lasing at 1557.1 nm is temperature controlled. The operating temperature is maintained at 23 °C. DC current is provided from a current controller. The laser diode has a threshold current of 41.6 mA. The operating bias current is selected at 83.2 mA which is twice the threshold current. A sinusoidal rf subcarrier at 0.3 MHz is amplitude modulated by an audio frequency signal – once with frequency 3 kHz and next with frequency 10 kHz. The InGaAs photodiode (PD) has a bandwidth of 1.2 GHz. The

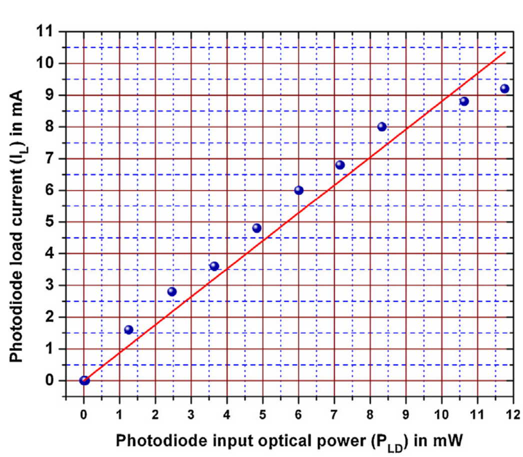

Fig. 2. InGaAs photodiode responsivity characteristics.

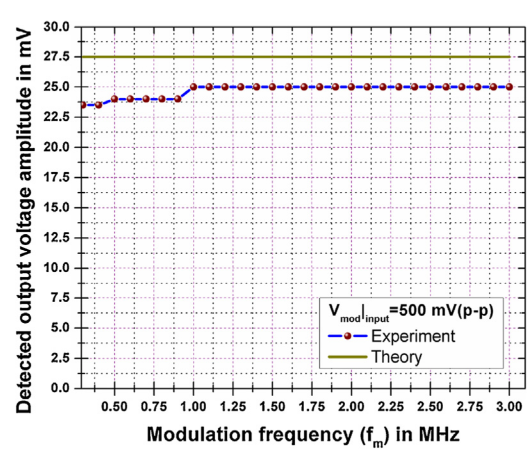

Fig. 4. Modulation frequency response of the laser diode for IM index = 12%. Modulation signal is applied to the LD mount through a bias tee.