CALIBRATION OF OPTICAL RECEIVERS AND MODULATORS USING AN OPTICAL HETERODYNE TECHNIQUE

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Abstract

The frequency response of optical receivers are accurately calibrated by measuring a heterodyne signal generated by mixing two Nd:YAG ring lasers. This heterodyne system offers more than 50 dB of dynamic range. Calibration of optical phase and amplitude modulators is achieved by downconverting a sideband of the modulated optical carrier to a fixed IF frequency with another laser. This technique eliminates the need for a high speed receiver.

Introduction

The Nd:YAG ring laser [1,2] is capable of generating a stable and narrow linewidth optical signal. By mixing the beams of two Nd:YAG ring lasers, a heterodyne signal at the beat frequency of the two lasers is generated. The wavelength of the lasers can be controlled by varying the temperature of the YAG crystals. Thus, the frequency of the heterodyne signal can be swept over a wide range to accurately characterize the frequency response of an optical receiver. This dual YAG system is capable of generating beat frequencies from DC to more than 100 GHz with better than 50 dB dynamic range.

The calibration of an optical amplitude modulator is often performed by direct measurement with a calibrated receiver. However, such technique can not measure the response of a phase modulator. In addition, as the bandwidth of the modulators increases it is important to develop techniques which do not depend on the availability of high speed calibrated receivers. The technique we have developed uses two Nd:YAG lasers, one passing through the modulator, the other functioning as a local oscillator to convert one of the side bands of the modulated carrier to a fixed IF frequency. This technique eliminates the need for a high-speed photoreceiver, has a good signal-to-noise-ratio, and makes measurement of phase modulator frequency response possible.

Optical Receiver Calibration

The laser used in this experiment is a diode laser pumped monolithic unidirectional ring oscillator which oscillates on the 1319 nm Nd:YAG transition [2]. It operates in a single mode with less than 3 KHz linewidth (Fig. 1) and a very stable frequency. These characteristics of this Nd: YAG ring laser make it an attractive optical source for precise calibration of the frequency response of optical devices. The

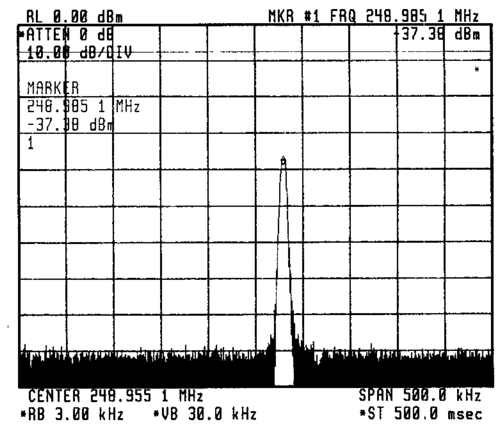

Figure 1: Heterodyne signal of two Nd:YAG ring lasers with linewidth less than 3 KHz FWHM.

schematic diagram for calibration of discrete photodiodes and optical receivers is shown in Fig. 2. The YAG laser temperature and the spectrum analyzer are controlled by a computer. The frequency vs. temperature behavior of this YAG laser heterodyne system is characterized by fixing the temperature of one YAG while sweeping the temperature of the other. The beat frequency of the two YAG lasers is measured and plotted vs. temperature in Fig. 3.

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There are mode hops which occur with approximately 12 GHz spacing, which are expected from the length of the optical path in the ring. For frequency sweeps of of more than 12 GHz, more than one frequency vs.temperature tuning band is used. The data from two or more bands are then pieced together to form a continuous sweep. Fig. 4(a) shows the uncalibrated frequency response of an optical receiver with an InP/InGaAs high speed photodiode [3]. The photo-current of the receiver and input optical power from the YAG lasers are also measured as shown in (Fig. 4(b), (c)) and show less than 0.5 dB variation during the measurement. The final calibrated frequency response of the receiver is obtained by substracting errors due to the cable, the spectrum analyzer and the variation in optical power. The final response is shown in Fig. 5. The repeatability of the measurement is better than +/-0.5 dB for the 22 GHz frequency range.

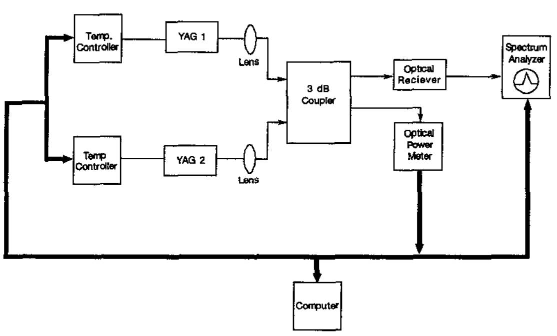

Figure 2: Optical heterodyne measurement system for optical receiver.

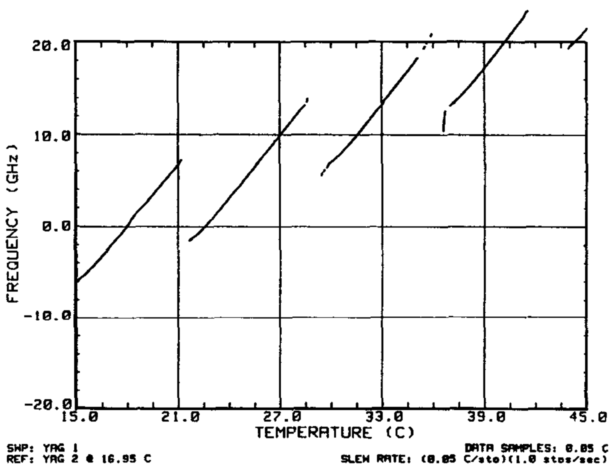

Figure 3: Beat frequency vs. YAG crystal temperature for the dual Nd:YAG ring lasers heterodyne system.

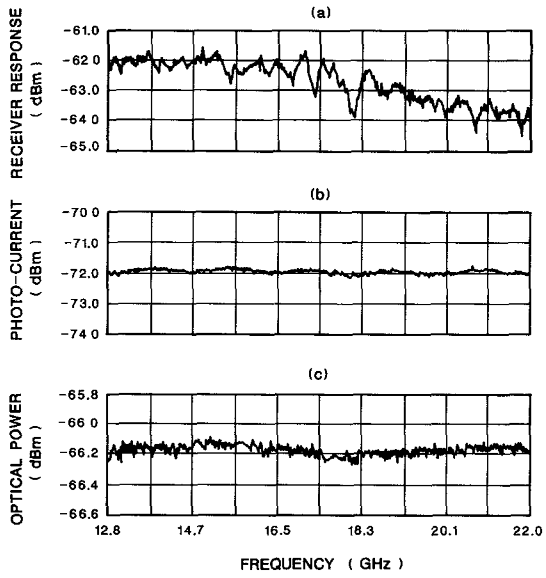

Figure 4: Measured responses of the optical receiver: (a) the frequency response (b) the photo-current and (c) input optical power.

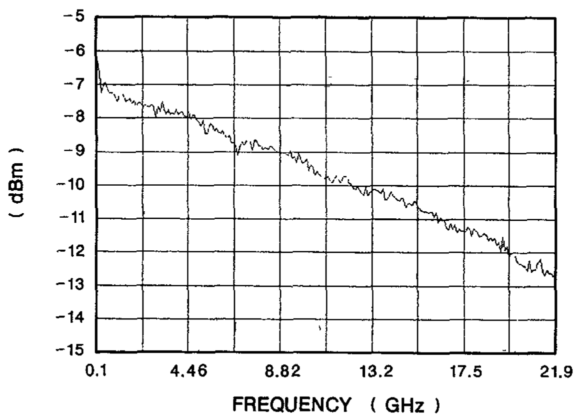

Figure 5: The final calibrated frequency response of the optical receiver.

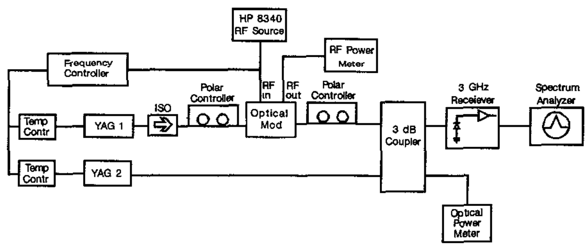

Figure 6: Optical heterodyne measurement system for an optical modulator.

Optical Modulator Calibration

The measurement setup for an optical modulator calibration is shown in Fig. 6. For an amplitude modulator, the signal detected at the spectrum analyzer consists of the following components:

(a) $M(f) = I_1^2 \cos \omega_m t$
(modulated signal detected directly)

(b) $I_1 \cdot I_2 \cos(\omega_1 - \omega_2)t$
(heterodyne signal of two lasers)

(c) $M(f) \cdot I_1 \cdot I_2 \cos(\omega_1 - \omega_2 \pm \omega_m)t$
(sidebands of the carrier)

where M(f) is the modulation index of the modulator I_1, I_2, ω_1, ω_2 are intensity and frequency of the lasers respectively and ω_m is the modulation frequency of the modulator. The frequency of the lower sideband ($\omega_1 - \omega_2 - \omega_m$) can be held at a fixed IF frequency by tracking the modulation frequency ω_m and the lasers beat frequency ($\omega_1 - \omega_2$). This technique does not require precise calibration of the receiver and the spectrum analyzer since measurements are made at a single frequency. In addition, the signal strength of the sidebands is enhanced by the much larger signal from the L.O. laser. Fig. 7 shows the signals displayed on the spectrum analyzer. The sideband signal is 10 dB larger than the directly detected signal. Fig. 8 shows the measured frequency response of a fiber pigtailed {++-+} phase reversal electrode amplitude modulator [4] to 26.5 GHz. The response of an un-coded modulator is also plotted and shows the predicted high frequency roll-off compared with the coded device.

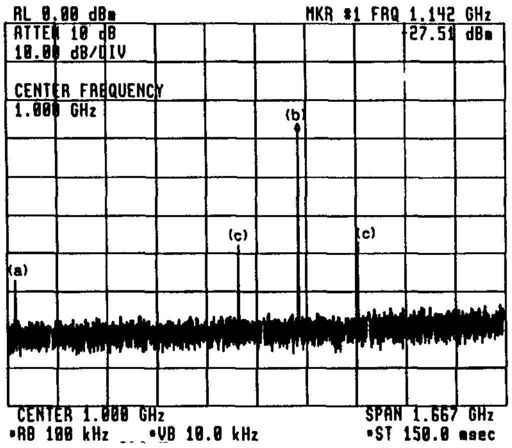

Figure 7: Signals detected at the spectrum analyzer for the amplitude modulator measurement : (a) directly modulated signal (b) heterodyne signal of two lasers and (c) sidebands of the carrier.

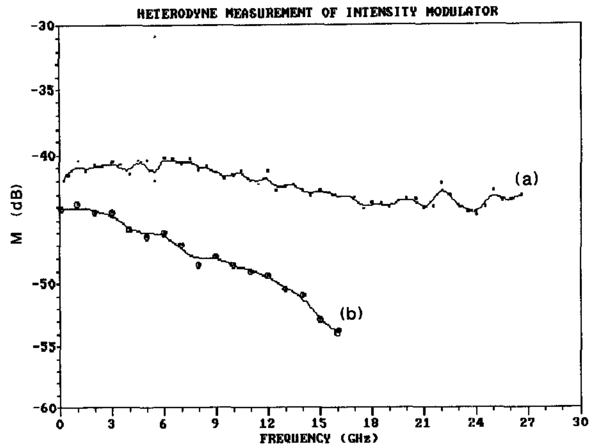

Figure 8: Measured frequency response of the amplitude modulators: (a) {++-+} phase reversal electrode amplitude modulator and (b) uncoded device.

For the phase modulator with a phase modulated signal of:

$$I_1 e^{i\omega_m t} e^{iM \sin \omega_m t}$$

the spectrum detected at the spectrum analyzer consists of the following components:

(a) $I_1 \cdot I_2 \cos(\omega_1 - \omega_2)t \, J_0(M)$
(heterodyne signal of two lasers)

(b) $I_1 \cdot I_2 \cos(\omega_1 - \omega_2 \pm \omega_m)t \, J_1(M)$
(fundamental sidebands of the carrier)

(c) $I_1 \cdot I_2 \cos(\omega_1 - \omega_2 \pm 2\omega_m)t \, J_2(M) + \cdots$
(higher harmonics sidebands)

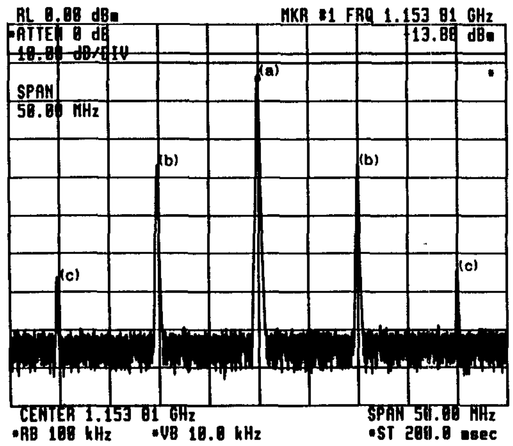

Figure 9: Signal detected at the spectrum analyzer for the phase modulator: (a) heterodyne signal of two lasers (b) fundamental sidebands of the carrier and (c) sidebands at the second harmonic.

They are displayed on the spectrum analyzer as shown in Fig. 9. For a small signal modulation:

$$J_1(M) \simeq M/2$$

The modulation index M(f) of the phase modulator can be obtained by measuring one of the sidebands. In Fig. 10, M(f) is plotted as a function of frequency for a phase modulator without phase reversals. M(f) is measured by tracking one of the sidebands with the local oscillator laser. The measured response shows good agreement with the theoretical curve. In addition to measuring the frequency response, the phase modulation efficiency can obtained by measuring the sideband amplitude as a function of the driving voltage. The modulation efficiency of this type of phase modulator is measured to be 0.14 rad/volt which agrees well with the expected value calculated from design parameters.

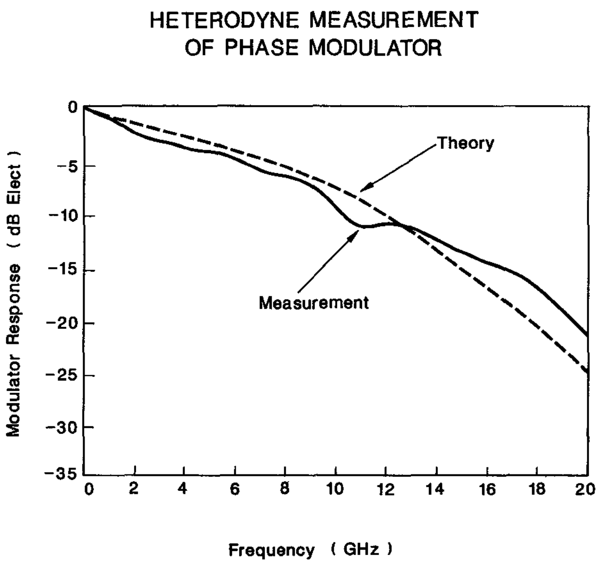

Figure 10: Measured and calculated frequency response of the phase modulator.

Conclusion

A dual Nd:YAG ring laser heterodyne system for the calibration of optical receivers has been demonstrated. Such system can potentially be used as a calibration standard for optical receivers and photodiodes. This heterodyne system is also used to measure the response of both phase and amplitude modulators without the need and precise calibration of a high speed receiver, and provides an extended the dynamic range in these measurement.

Acknowledgement

We would like to thank Rick Trutna and Dave Donald for their assistance in setting up the YAG heterodyne system, Paul Hernday and Rory Van Tuyl for consultation in receiver calibration, Joe Ballantyne, Rob Chavez and Dennis Derrickson for the computer software program used in the measurement.

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