Optica Applicata, Vol. XIII, No. 3, 1983

Frequency response of photodetector measurements by means of heterodyne and interferometric techniques of detection

Krzysztof M. Abramski

Institute of Telecommunication and Acoustics, Technical University of Wrocław, Poland.

Heterodyne and interferometric detection has been used to measure the frequency response of photodetectors. Descriptions of measurements and experimental set-ups are presented. Both methods are well suited for designation frequency response.

1. Introduction

As far as the application of photodetectors are concerned, the frequency response is one of the most important parameters. It determines the detectability of fast optical phenomena such as short pulses or beating. The frequency response is usually measured by the analysis of time response of photodetectors detecting the short optical pulse or by the measurement of modulation characteristic.

The heterodyne and interferometric detection are other methods of frequency response $S(f)$ measurements. They may be more accurate and easier in practice.

2. Heterodyne technique of detection

The intensity of beating two single-mode laser beams operating on frequencies ν_1, ν_2 may be expressed in the form

$$I(t) = E_1^2(\nu)+E_2^2(\nu)+2E_1(\nu_1)E_2(\nu_2)\cos\{[2\pi(\nu_1-\nu_2)t]+\Phi(t)\} = I_a+I_h(t) \tag{1}$$

where $E_1(\nu_1), E_2(\nu_2)$ — amplitudes of electric-field intensity of both waves,

I_0 — mean intensity of radiation,

$I_h(t)$ — harmonic component of radiation (called heterodyne signal below),

$\Phi(t)$ — phase fluctuation of heterodyne signal.

If one of the laser frequencies is tuned linearly at the rate a (which can be simply performed by means of PZT driver), the heterodyne signal $I_h(t)$ may be written as

$$I_h(t) = I_{h0}\cos\{2\pi[(\nu_1+at)-\nu_2]t+\Phi(t)\}. \tag{2}$$

Derivative of the phase fluctuation $d\Phi(t)/dt$ presents the frequency fluctuation of heterodyne signal due to nonstability of lasers. When short-term fluctuations of different laser frequency are less than bandpass of photodetector, $\Phi(t)$ in Eq. (2) may be neglected. Heterodyne signal is then a useful wobbling signal to measure the frequency response of investigated photodetector [1]. It should be noted that heterodyne component of intensity I_h falls on the photodetector together with the mean intensity I_0. The ratio I_h/I_0 may vary from 0 to 1 by a precize adjustment of heterodyne optical set-up [2]. The width of emission laser line limits the range of frequency tunability. If the bandpass of investigated photodetector is comparable with the width of the laser line the heterodyne signal $I_h(t)$ is weighed by the profile of output power line of tuned laser.

Heterodyne method is particularly useful for investigation of "fast" photodetectors. If the bandpass of photodetector is larger then the width of emission laser line, the measurement may be achieved by isotopical shift of emission line of the laser used. This problem may be eliminated if dye or waveguide laser are applied.

2.1. Experimental results

Figure 1 shows experimental block diagram for measurement of frequency response of InAs photodiode (J-12 LD, Judson) at $\lambda = 3.39$ μm (He-Ne lasers). In order to mark the frequency scale the heterodyne signal trains from photodetector to frequency discriminator tuned on $\nu_0 = 2.5$ MHz. The oscilloscope

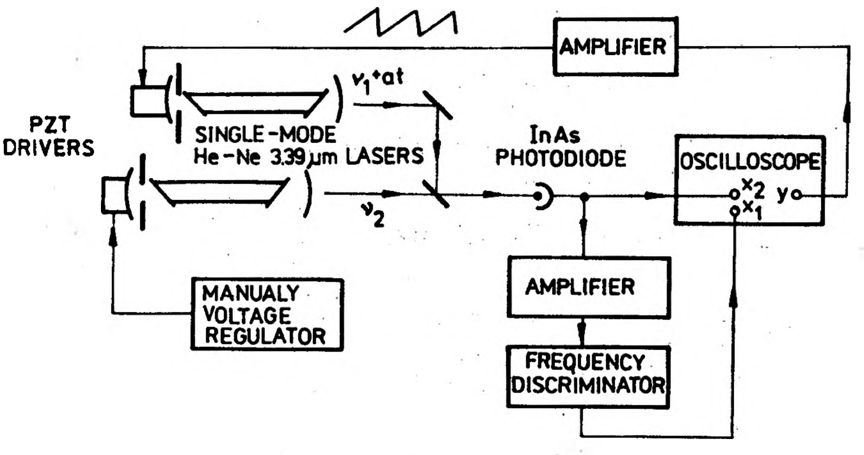


Fig. 1. Block diagram of frequency response measurement by means of heterodyne detection

record in Fig. 2 shows the simultaneous observation of heterodyne signal and discriminant signal. The frequency response of the investigated photodiode is presented in Fig. 3.

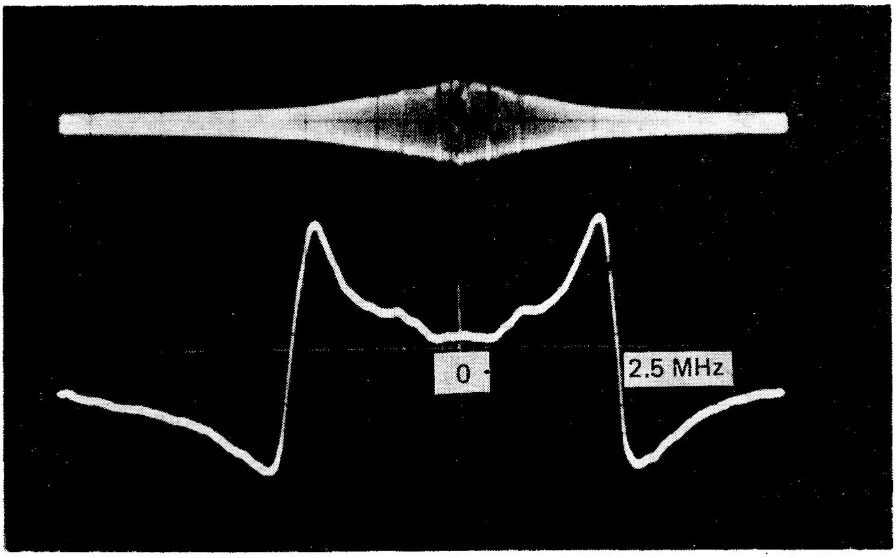


Fig. 2. Simultaneous oscilloscope records of heterodyne and discriminant signals

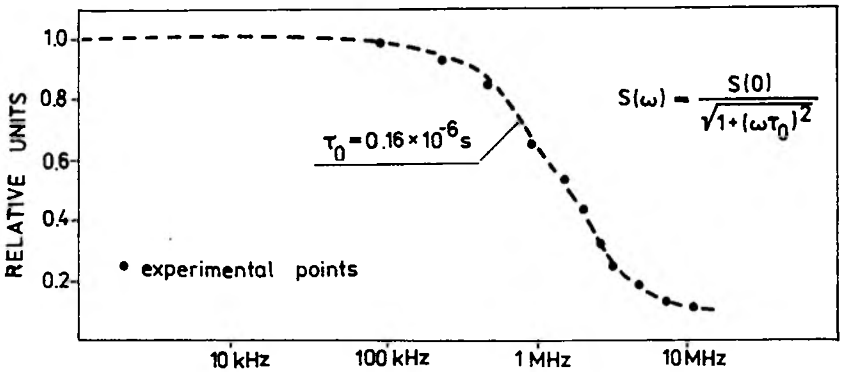


Fig. 3. Frequency response of InAs photodiode at 3.39 μm measured by means of heterodyne detection

3. Interferometric technique of detection

The beating of two laser beams originating from the same source is an example of interference ($\nu_1 = \nu_2$). In term $I_h(t)$ in Eq. (2) represents the interferometric pattern with small phase fluctuation $\Phi_0(t)$ caused by the optical path difference disturbances in interferometer. In this case the term $I_h(t)$ may be called an interferometric signal and written as

$$I_i(t) = I_{i0}\cos[\Phi_0(t)]. \tag{3}$$

In order to obtain a controlled signal $I_i(t)$ one of the arms of interferometer should be tuned in the well-known way [3]. If the displacement of one mirror in interferometer is $x(t)$, the phase of interferometric signal is changed due to Doppler effect

$$\Phi(t) = \frac{4\pi x(t)}{\lambda}, \tag{4}$$

and

$$I_i(t) = I_{i0}\cos\left[\frac{4\pi x(t)}{\lambda} + \Phi_0(t)\right]. \tag{5}$$

For a well stabilized interferometer $\Phi_0(t)$ is less than π and it may be neglected. If $x(t)$ is the saw-tooth function, $I_i(t)$ is the useful wobbling signal, like $I_h(t)$ in Eq. (2). In practice a fast saw-tooth mechanical displacement with a large amplitude is difficult to obtain and that is why the harmonic tunning should be applied [4]

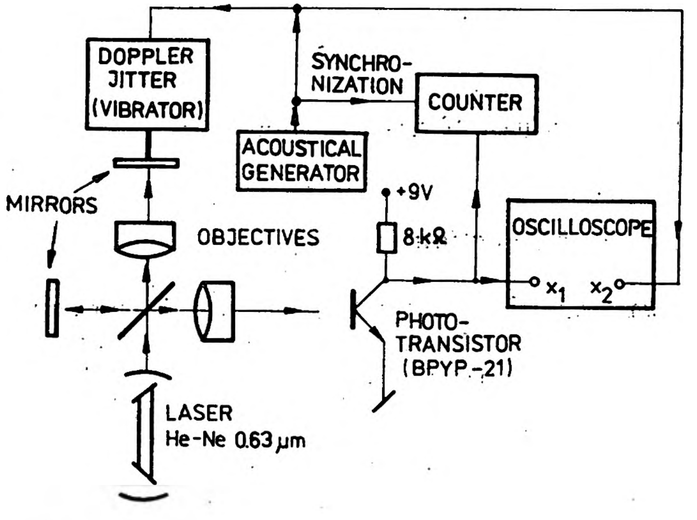
$$x(t) = x_0\sin(\Omega t). \tag{6}$$

The interferometric signal $I_i(t)$ has the form

$$I_i(t) = I_{i0}\cos\left[\frac{4\pi x_0}{\lambda}\sin(\Omega t)\right]. \tag{7}$$

The instantaneous frequency of signal $I_i(t)$ is

$$\nu(t) = \frac{1}{2\pi}\frac{d\Phi(t)}{dt} = \frac{2x_0}{\lambda}\cos(\Omega t), \tag{8}$$



g. 4. Block diagram of frequency response measurements by means of interferometric detection

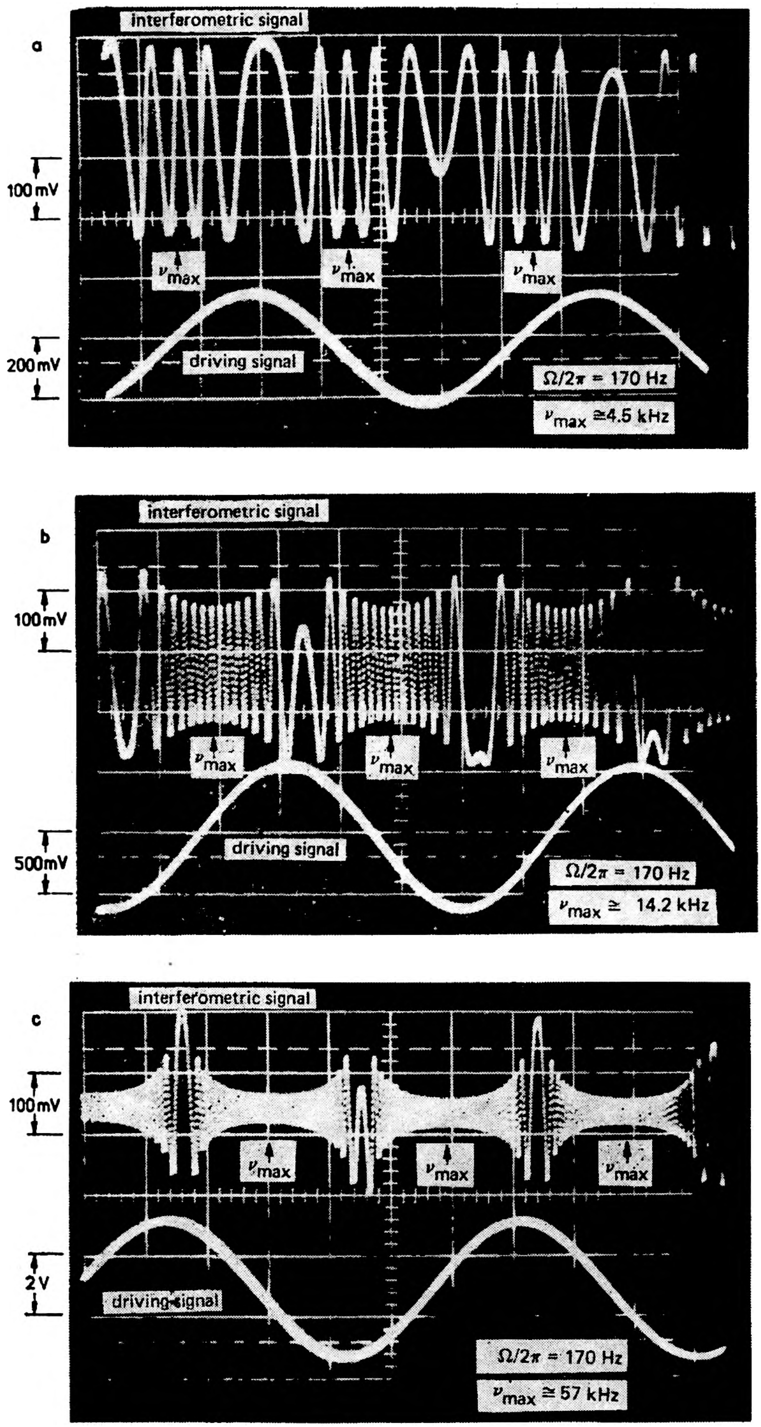


Fig. 5. Oscilloscope records of interferometric and driving signals for different amplitude of vibration

and for $\Omega t = k\pi$ the maximum value

$$\nu_{\max} = \frac{1}{2\pi} \frac{d\Phi(t)}{dt}\bigg|_{\Omega t = k\pi} = \frac{2\Omega x_0}{\lambda} \tag{9}$$

is obtained.

The changes in amplitude x_0 and angular frequency Ω permit to obtain the optimal values of frequency deviation. By detecting the interferometric signal for difference $\nu_{\max}$ the frequency response characteristic of investigated photodetector may be easily found.

3.1. Experimental results

The author applied the above method to measurement of frequency response characteristic of phototransistor (BPYP–21, UNITRA–CEMI) at $\lambda = 0.63$ µm (He-Ne 0.63 µm lasers). The experimentsl set-up is shown in Fig. 4. One mirror of the laser interferometer was placed on the mechanical vibrator. The amplitude of displacement x_0 was measured by counting the interferometric fringes in one period $T = 2\pi/\Omega$ of driving signal. The examples of interferometric signals detected by phototransistor for different x_0 are presented in Fig. 5.

In order to compare the two presented methods the heterodyne measurements of BPYP–21 phototransistor have been performed in the heterodyne system with He-Ne 0.63 µm lasers. Figure 6 shows the frequency response characteristic of phototransistor measured by means of both the above methods.

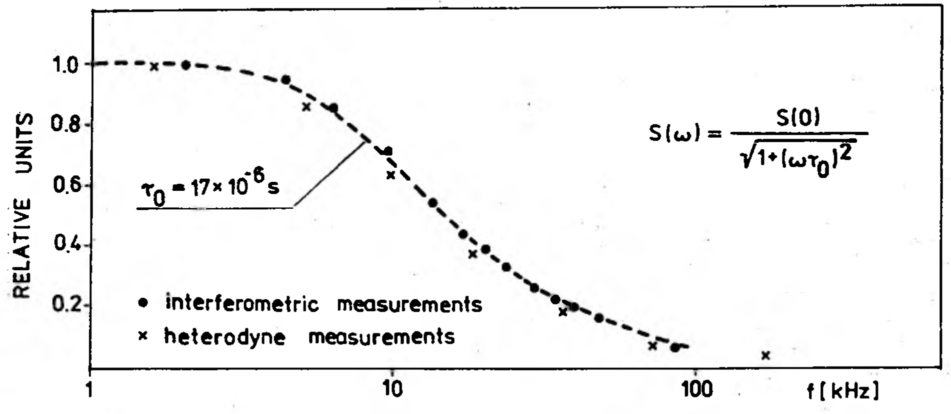


Fig. 6. Frequency response of phototransistor BPYP–21 measured by means of interferometric and heterodyne detection

4. Summary

The frequency response of photodetectors can be found by means of heterodyne or interferometric detection described above. Unlike the traditional methods the wobbling signal may be obtained when wide-band modulators are not applied.

References

[1] Buczek C. J., Picus G. S., Appl. Phys. Lett. **11** (1967), 125–126.
[2] Abramski K. M., Pliński E. F., Optica Applicata **11** (1981), 563–570.
[3] Vanecyan R. A., Tychinskaya M. P., Zakharov V. P., Nikolaev O. A., Tishchenko Kvantovaya V. A., Elektronika, No. 4 (1971), 27–33.
[4] Masatuka N., Toshimitsu M., Toshiharu T., J. Appl. Phys. **50** (1979), 2544–2547

Received January 4 1983,
in revised form April 25, 1983

Измерения частотной характеристики фотодетекторов при использовании гетеродинного и интерференционного детектирования

Гетеродинное и интерференционное детектирование было использовано для измерения частотной характеристики фотодетекторов. Представлены измерения и экспериментальные установки. Оба метода удобны для определения частотных характеристик фотодетекторов.

Проверила Малгожата Хейдрих