High-bandwidth photodiode frequency-response characterization method based on the photomixing technique

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ABSTRACT

In this work we report on a reliable and low-cost frequency-response characterization method for high-bandwidth photodiodes. Using the photomixing technique, we were able to experimentally characterize the electrical response of commercial devices up to 60GHz using both DFB and low-cost Fabry-Perot laser sources.

Keywords: high-bandwidth photodiodes, millimeter-wave generation, frequency-response measurement.

1. INTRODUCTION

Conventional high-frequency (tens of GHz) optical device characterization techniques normally require high-cost RF instrumentation (e.g. network analyzers, high-frequency generators and modulators). RF amplitude-modulation frequency-response measurements are critical because they are strongly affected by electro-magnetic interference (EMI) effects. More evolute techniques, like pulse-response and electro-optical sampling,[1] do not give a direct measure of the frequency-response curve and they need some data post-processing (i.e deconvolution). To avoid these drawbacks, the high-frequency electrical probe signal can be generated through coherent beating on the photodiode-under-test of two optical wavelengths, which can be provided either by two modes of a multimode laser[2] or by the light emitted by two separate laser sources.[3] This technique is known as *photomixing* and it is mainly applied to millimeter- and submillimeter-wave generation.[4]

The photomixing method, applied in particular to photodiode frequency-response characterization, may present some difficulties. In fact, the wavelength difference between the two probe lasers must be kept constant to generate a stable single frequency electrical signal; besides, we also need the capability to continuously tune one of the two lasers in order to change the electrical beat signal frequency, thus obtaining the desired frequency-response measurement through wavelength sweeping. In spite of these drawbacks, through this technique, we were able to experimentally characterize the electrical response of commercial photodiodes up to 60GHz using both DFB and low-cost Fabry-Perot laser sources.

2. EXPERIMENTAL SETUP

The all-fiber experimental setup for photodiode frequency-response characterization using the photomixing technique is shown in Figure 1. The two lasers (Fabry-Perot or DFB) are used to generate the desired electrical beat frequency via coherent heterodyne detection of the two wavelengths on the device-under-test (DUT); optical isolators are needed in order to avoid back-injection, which may lead to laser instability or chaos. Besides, a polarization controller is necessary to maximize the laser beams polarization overlap onto the photodiode, thus increasing the power of the beating electrical signal. The wavelength separation (i.e. the electrical signal frequency) can be changed by tuning either the temperature or current of one of the two sources; typical values of temperature and current tuning for a Fabry-Perot laser are respectively 40GHz/°C and 4GHz/mA.

The two laser beams enter the two input fibers of a 50/50 optical coupler; one of the two coupler output fibers is connected to an optical spectrum analyzer (OSA) that acts as a coarse wavelength separation monitor: in fact, observing the OSA trace, it is possible to control the degree of laser wavelength overlap within the resolution limitation of the instrument.

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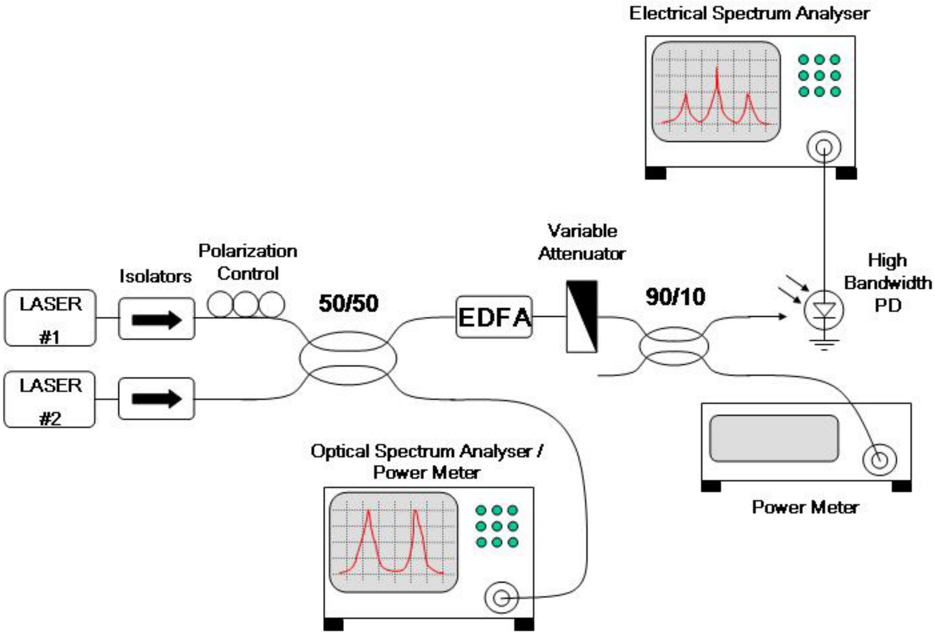

Figure 1. Experimental setup for photodiode frequency-response characterization using the photomixing technique.

The other coupler output fiber is directly connected to the DUT. In the case of frequency-response characterization in the optical-communications third-window (i.e. @ 1550nm), it is possible to add an erbium-doped fiber amplifier (EDFA) and an optical variable attenuator, as shown in Figure 1: this is important if we want to observe the frequency-response dependence on the input optical power; an additional 90/10 coupler is introduced to monitor the actual optical power injected in the photodiode.

Finally, the photodiode-under-test is connected to an electrical spectrum analyzer, that measures the amplitude of the beat electrical signal. In Figure 2 we show an example of the spectrum of a signal at a frequency of about 50GHz, obtained by beating two 1550nm DFB lasers on a 60GHz-bandwidth photodiode.

The frequency of this signal depends only on the wavelength separation of the two lasers, while the amplitude depends on the optical power of the two lasers, the photodiode responsivity, the polarization overlap and, above all, the photodiode frequency-response. By tuning the electrical beat signal frequency (i.e. changing the wavelength of one of the two lasers) while keeping the other parameters constant (i.e. optical power, polarization, etc.) and measuring the beating signal peak amplitude for each frequency value, we can obtain an amplitude vs. frequency curve which is directly proportional to the device frequency-response.

It is important to say that, in particular in the case we decide to use two Fabry-Perot laser sources, the beating electrical signal is characterized by a strong frequency fluctuation, caused by the relative movement of the two wavelengths, with a typical temporal drift of about 10MHz/s. This phenomenon increases the measurement difficulty because of the rapid movement of the electrical beat signal line on the electrical spectrum analyzer (ESA) trace; besides, this fluctuation, being generally faster than the ESA trace sweep time, can also lead to substantial visualization errors. This problem can be easily solved by using the *max-hold* feature (very common in conventional electrical spectrum analyzers), which permits to accumulate continuously on the ESA trace the maximum values measured for each frequency.

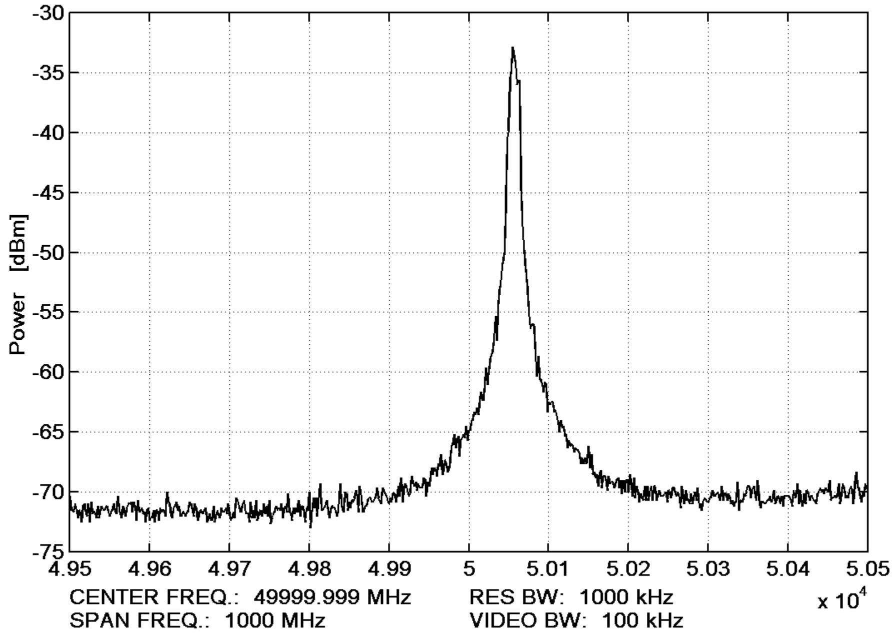

Figure 2. Example of the beating signal obtained by coherent heterodyne detection of two 1550nm DFB lasers on a 60GHz commercial photodiode; the signal frequency is of about 50GHz and the peak amplitude is -33dBm.

3. MEASUREMENT PROCEDURE

In this section we shortly describe the measurement procedure used to characterize the photodiode frequency-response through the experimental setup described in Section 2. At first, the frequency difference between the two laser sources is changed with the help of the optical spectrum analyzer until the two emission lines are completely overlapped; in this situation the frequency difference between the two lasers is smaller than the instrument resolution (in our case 0.1nm, which corresponds to 40GHz @ 850nm and 12.5GHz @ 1550nm). By looking at the electrical spectrum analyzer trace (with the help of a suitable electrical mixer for very high-frequency signals), it should now be possible to observe the beating signal, which helps to finely tune the signal frequency to a precise value.

The next step is to set the ESA in the *max-hold* mode; then, changing continuously the beating signal frequency through either laser temperature or current tuning, we obtain on the ESA screen a trace which is related to the frequency response of the photodiode-under-test. An example of the ESA trace raw data at this point of the procedure is shown in Figure 3. This plot is referred to a commercial 60GHz-bandwidth photodiode working at 1550nm with an applied reverse voltage of about -3V.

As we can see from Figure 3, the curve obtained with the *max-hold* technique is full of peaks and definitely not regular; this is due to the fact that the frequency difference tuning is not completely continuous. For this reason, it is necessary to smooth the measured curve shown in Figure 3 through very simple data processing (i.e. finding the raw data curve envelope), obtaining the final frequency-response curve shown in Figure 4. As we can see, the photodiode bandwidth measured with the photomixing technique is 57GHz, which is very close to the nominal value.

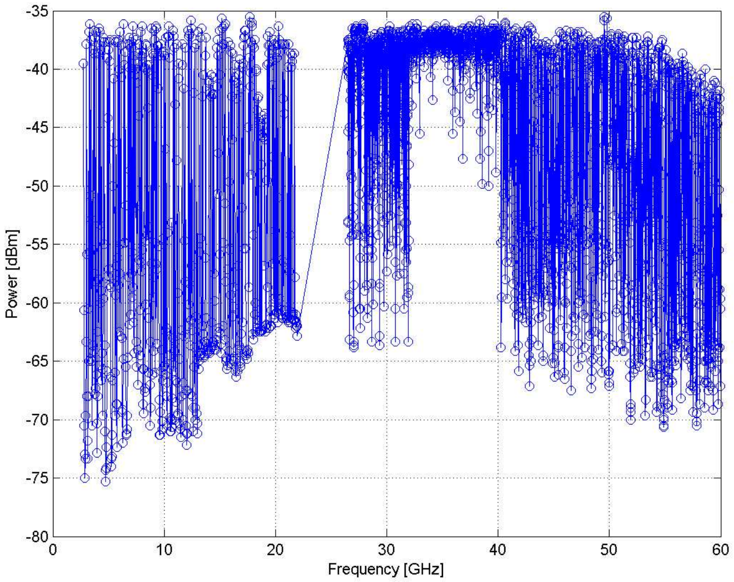

Figure 3. Example of raw data obtained from photodiode frequency-response characterization using the photomixing technique. The trace is obtained with the ESA *max-hold* mode and is relative to a commercial 60GHz-bandwidth photodiode working at 1550nm with an applied reverse voltage of about -3V.

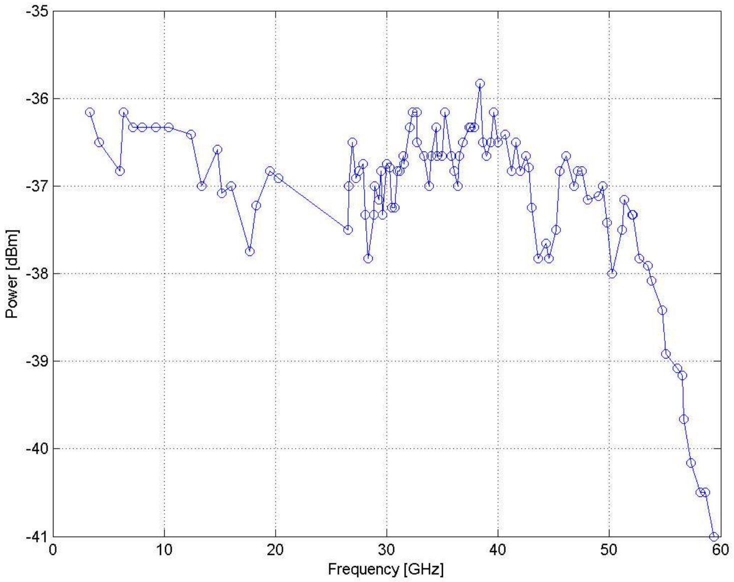

Figure 4. Example of smoothing of the frequency-response trace obtained with the ESA *max-hold* modality; the result shown here is relative the trace previously shown in Figure 3, relative to a commercial photodiode with a nominal bandwidth of 60GHz. As we can see, the photodiode bandwidth measured with the photomixing technique is 57GHz, which is very close to the nominal value.

4. EXPERIMENTAL RESULTS ON COMMERCIAL DEVICES

Through the procedure shown in the previous section, we were able to characterize the frequency-response of a variety of commercial devices, using both DFB and Fabry-Perot lasers working at a chosen wavelength; this section is aimed to show some of this experimental results.

In Figures 5, 6 and 7 we show the frequency-response characterization, obtained with two conventional third-window DFB lasers, of U^2T Photonics XPDV3020R p-i-n waveguide photodiode, working at 1550nm, having a nominal bandwidth of 60GHz. This device was characterized at three different bias voltage values: -1.5V, 0V and 300mV (small positive bias voltage). For -1.5V bias, we measured a bandwidth of about 57GHz, which is very close to the nominal value; changing the reverse voltage to 0V, we have a bandwidth reduction from 57 to 50GHz. A consistent change in the frequency-response curve occurs when applying a small positive voltage (300mV). Figure 7 shows the appearance of a new cut-off frequency due to carrier diffusion bandwidth limitation, which becomes important in p-i-n structures only applying a direct bias: consequently, device bandwidth is limited to about 10GHz.

Another example of frequency-response characterization using the photomixing technique is shown in Figure 8; this frequency-response curve is relative to NewFocus 1004 40GHz photodiode, working at 830nm; it's important to remark that this measurement was obtained using two low-cost 830nm Fabry-perot single-mode lasers. As shown in the figure, measured bandwidth is in very good agreement with the nominal value.

5. CONCLUSIONS

This work shows that the photomixing technique permits to characterize the frequency-response of optical devices in a relative simple way and with no need of high-cost RF instrumentation or laser sources; some examples of application to commercial devices has been shown in Section 4.

In the future this technique could be extended to high-bandwidth dispersion measurement of optical devices and fibers; besides, changing the optical power injected in the device-under-test, it should be possible to study the dependence of detector bandwidth on power saturation effects.

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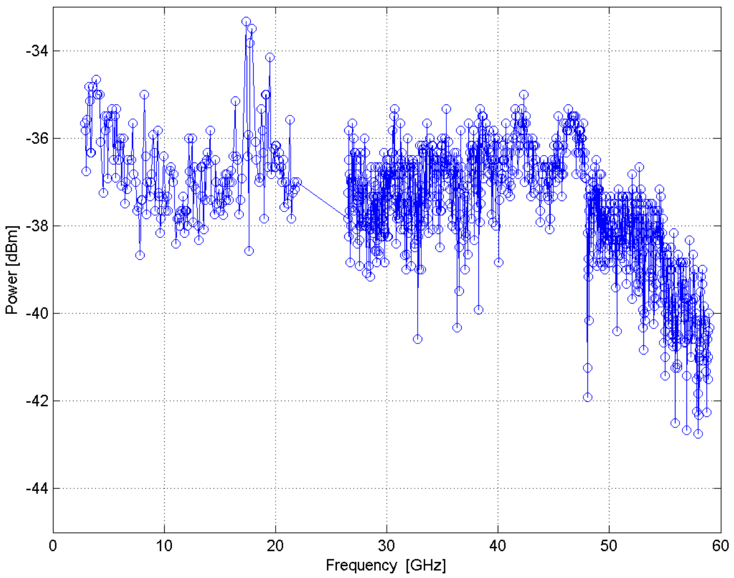

Figure 5. Frequency-response characterization of U^{2}T Photonics XPDV3020R photodiode, biased at -1.5V. Measured cut-off frequency is 57GHz, in good agreement with the 60GHz nominal value.

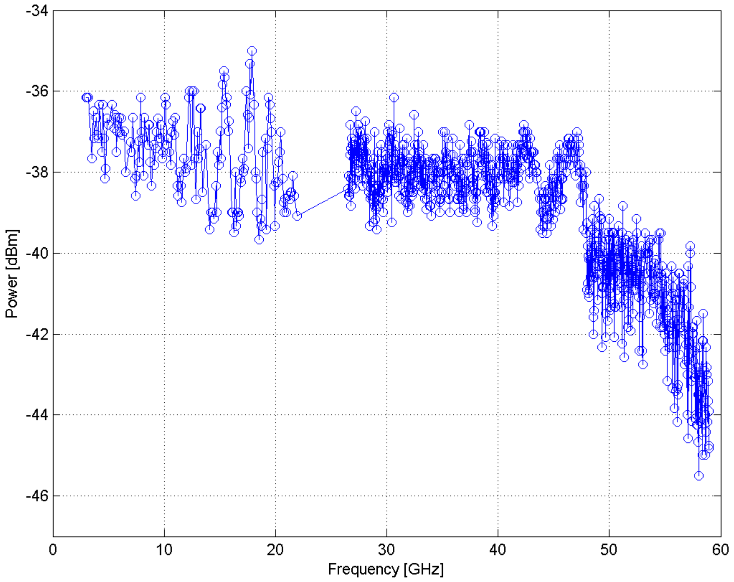

Figure 6. Frequency-response characterization of U^{2}T Photonics XPDV3020R photodiode, biased at 0V. Due to the reverse voltage decrease, measured bandwidth is reduced to 50GHz.

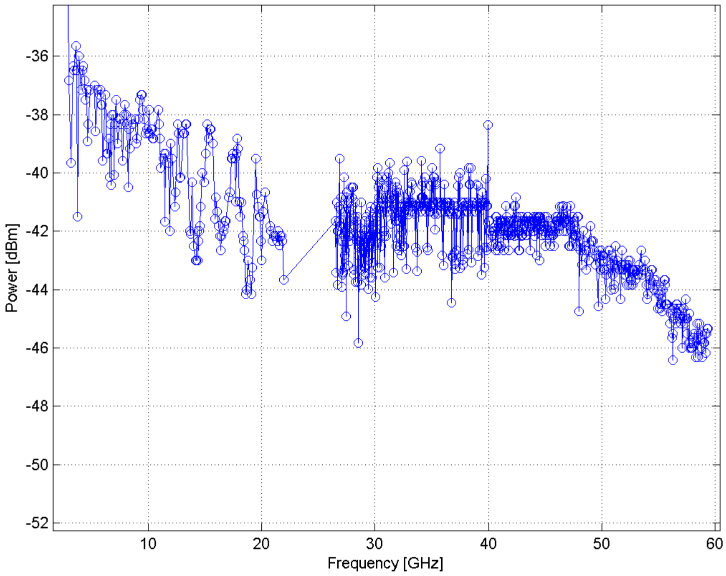

Figure 7. Frequency-response characterization of U^{2}T Photonics XPDV3020R photodiode, biased with a positive voltage (300mV). Measured bandwidth is of about 10GHz. It can be noted that the shape of the frequency-response curve changes with respect to Figures 5 and 6, because of the effect of carrier diffusion cut-off frequency.

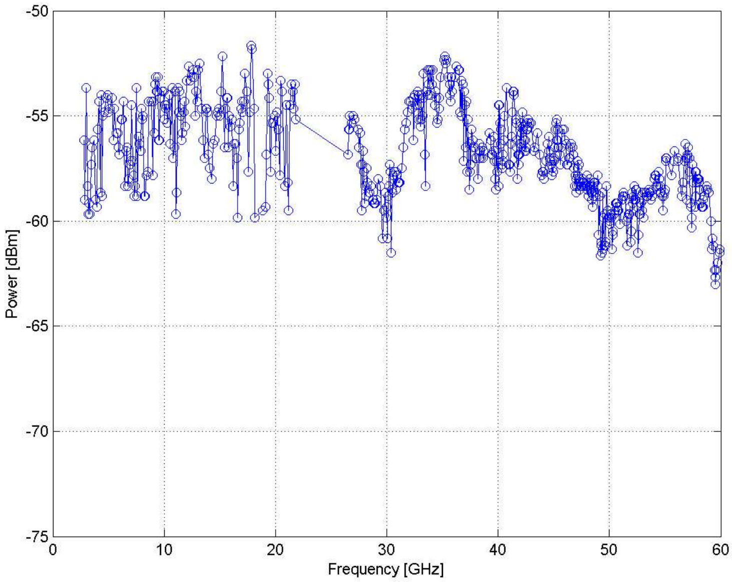

Figure 8. Frequency-response characterization of NewFocus 1004 40GHz photodiode, working at 830nm; measured bandwidth is approximately 40GHz. This characterization was obtained using two low-cost 830nm Fabry-perot lasers.