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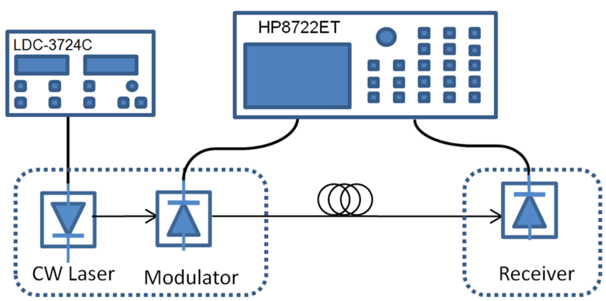
Xuming Wu
Jiangwei Man
Liang Xie
Jianguo Liu
Yu Liu
Ninghua Zhu, Member, IEEE



Modulator	Receiver	Results
EAM	Photodetector	S_{21}^{I}
DFB Laser	Photodetector	S_{21}^{II}
DFB Laser	EAM	S_{21}^{III}

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A New Method for Measuring the Frequency Response of Broadband Optoelectronic Devices

Xuming Wu, Jiangwei Man, Liang Xie, Jianguo Liu, Yu Liu, and Ninghua Zhu, *Member, IEEE*

State Key Laboratory on Integrated Optoelectronics, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

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Abstract: A new and simple method based on the frequency-sweep method for measuring the frequency response of broadband optoelectronic devices is demonstrated. The electro-absorption modulator (EAM) can function as both modulator and receiver with the same frequency response. With this property, the frequency responses of a distributed feedback (DFB) laser at different bias currents were measured from dc to 20 GHz by the method. The results were quite identical with the results measured by the frequency-sweep method with broadband photodetector. Besides, the measurement bandwidth is not limited by the bandwidths of the devices, and the results are not influenced by the bandwidths of the EAM or other devices.

Index Terms: Broadband devices, DFB laser, electronic-absorption modulator, frequency response.

1. Introduction

With the development of optical-fiber communication, broadband optoelectronic devices including the direct modulation laser diodes, external modulators, and photodetectors have become more and more important. The bandwidth of the optoelectronic devices is needed to be higher and higher for the ultrahigh speed communication [1]. The bandwidth of the devices can be obtained by measuring the frequency responses of the devices. The frequency response of the device is a key parameter of the device, and it always consists of the intrinsic response of the chip, the parasitic parameters of the chip, and the parasitic parameters of the package [2]. In order to improve and develop the broadband optoelectronic devices, a lot of research works have been done on improving the response of the chip and optimizing the configuration of the package [3]. However, the improvements of the frequency response measurement systems are also necessary. Many methods have been proposed to measure the frequency responses of optoelectronic devices. The frequency-sweep method is a most common method, while a standard device with known response and higher bandwidth than the measurement frequency range is indispensable [4]–[6]. So the limitation of the measurement is decided by the bandwidth of the standard device [7]. Other

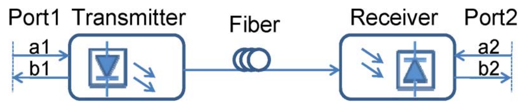

Fig. 1. Illustration of the transmission of the optoelectronic network.

methods such as the pulse spectrum analysis method [8], the optical heterodyne method, [9] and the optical two-tone method [10] are used to measure the response of the photodetector, but all these methods are quite complex and unpractical for ordinary measurements. Electro-absorption modulator (EAM) is widely used as external modulators in optical communication for its low chirp, high bandwidth, low driven voltage, and easy integration compared with other devices [11]. EAM can also be used in optical wavelengths conversion, generation of ultrashort laser pulse, and clock signal extraction [12]. For an EAM, it has the similar structure with a photodetector and they share the same transport properties [13]. The carrier escape times are the crucial factor of the frequency response of both the EAM and the photodetector, while the carrier escape times of both devices are biased dependent [14]. For the same EAM used as modulator or photodetector, its frequency responses are almost identical at the same bias voltage [15]. In this paper, we validated that the frequency response of an EAM used as a photodetector is the same as when it is used as a modulator. Based on this point, we develop a method to measure the frequency response of a DFB laser and a broadband photodetector with a relatively narrow-band EAM with the frequency-sweep method. The proposed method is quite simple, and the results were quite identical with the results measured by broadband devices with frequency-sweep method.

2. Operation Principle

For the optoelectronic devices used in microwave network, scattering parameters (S parameters) are always used to describe the frequency responses of the devices, which can indicate their operating characteristics including modulation frequency response and the microwave return loss. An ordinal optoelectronic network always includes a transmitter and a receiver shown in Fig. 1. For the transmitter is an electronic-optic conversion device and the receiver is an optic-electronic conversion device, the scatter matrixes of the transmitter and the receiver can be written as $S_t = \begin{bmatrix} \Gamma_t & 0 \\ G & 0 \end{bmatrix}$ and $S_r = \begin{bmatrix} 0 & 0 \\ R & \Gamma_r \end{bmatrix}$. Here, G and R are the transmission parameters, and Γ_t and Γ_r are the reflection parameters of the transmitter and the receiver. The reflection parameters are one-port parameters, and they can be measured directly by the frequency-sweep method. The scatting matrix for the whole optoelectronic network is

$$\begin{bmatrix} b1 \\ b2 \end{bmatrix} = \begin{bmatrix} \Gamma_t & 0 \\ RG & \Gamma r \end{bmatrix} \begin{bmatrix} a1 \\ a2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a1 \\ a2 \end{bmatrix}. \tag{1}$$

The transmission parameter for the whole network is $R * G$, so the R and G cannot be measured, respectively, with traditional method. In order to acquire the value of R by the frequency-sweep method, G should be known, and the bandwidth of the transmitter should be wider than the receiver. In order to measure G, R should also be certain, and the value of R is acquirable.

EAMs are always used as external modulators but also can be used as receivers. In order to validate the consistency of frequency responses of these two functions, we carried out our experiments shown in Fig. 2. Two commercial EAMs were used, while one was used as modulator and the other was used as receiver. A continuous wave laser was used as the light source and a calibrated vector network analyzer (VNA) was used to measure the frequency responses. When EAM1 was used as modulator and EAM2 was used as receiver, a transmission curve ${S_{21}}^a$ was measured. We changed the roles of the two EAMs. While EAM2 was used as modulator and EAM1 as receiver, another transmission curve ${S_{21}}^b$ was measured. The biased voltages of the EAMs were fixed when the roles of the EAMs were changed. The results are shown in Fig. 3. It is obvious that the two curves are almost the same. So we can assume that ${S_{21}}^a = {S_{21}}^b$. EAM1 and EAM2 are

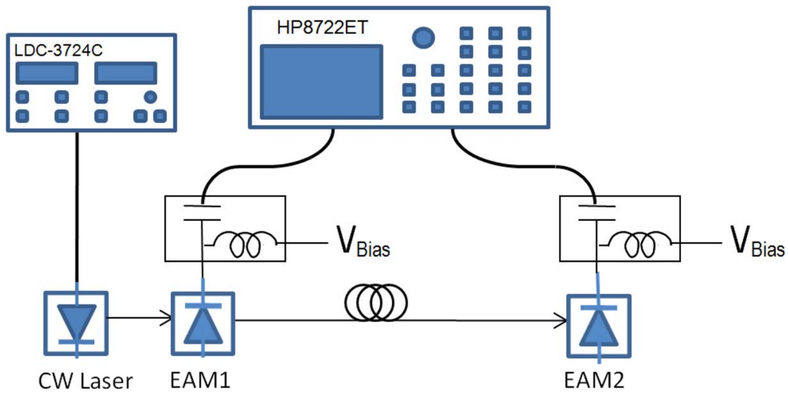

Fig. 2. Experimental setup to validate the consistency of the frequency responses of the EAM used as the modulator or the receiver. LDC-3724C is a commercial laser diode current source with temperature controller. HP8722ET is a 20 GHz 2-port VNA.

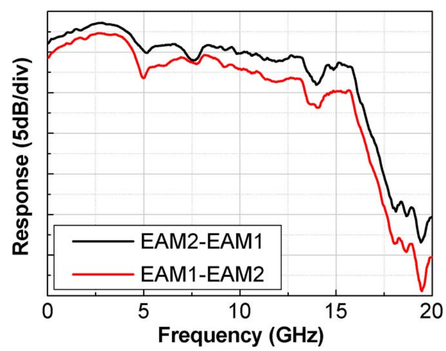

Fig. 3. Experimental results: the red curve is $S_{21}{}^{a}$ and the black curve is $S_{21}{}^{b}$.

two unrelated devices, so the same results can be obtained from other EAMs with the similar structure. From (1), we can get that

$$S_{21}{}^{a} = G_{\mathrm{EAM1}} R_{\mathrm{EAM2}} \quad (2)$$

$$S_{21}{}^{b} = G_{\mathrm{EAM2}} R_{\mathrm{EAM1}}. \quad (3)$$

For $S_{21}{}^{a} = S_{21}{}^{b}$, from (2) and (3), we can get that

$$R_{\mathrm{EAM1}}/G_{\mathrm{EAM1}} = R_{\mathrm{EAM2}}/G_{\mathrm{EAM2}} = \mathrm{C}. \quad (4)$$

C is a constant. The formulation (3) illuminates that the EAMs used as the modulator or the receiver have the same normalized frequency responses at the same biased voltage. The only difference between the EAM used as modulator and used as photodetector is the modulation power when it is biased at the same voltage. So we measured the reflection of the EAM when it worked as the modulator, and the results are shown in Fig. 4. It is clearly that the reflection does not change as the modulation power changes. It means that the modulation power do not influence the response of the EAM when the modulation power changed from -1 dBm to -13 dBm. For our measurements, the modulation power was always set at -5 dBm. So the frequency responses of the EAM used as modulator and as receiver are not influence by the modulation. Based on this property, we can obtain the frequency response of the EAM, and other optoelectronic devices can be measured by the EAMs.

The experiments in Fig. 5 were carried out. A directly modulated DFB laser was used as the transmitter, and a photodetector was used as the receiver. An EAM was used as both modulator

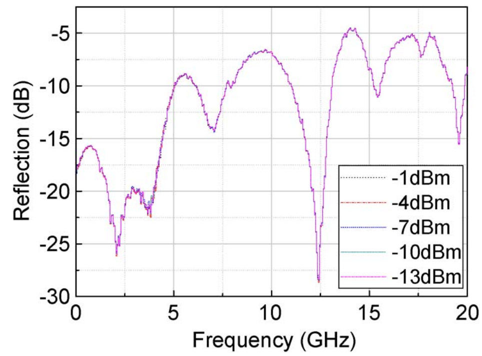

Fig. 4. Reflection of the EAM1 as the modulation power changed.

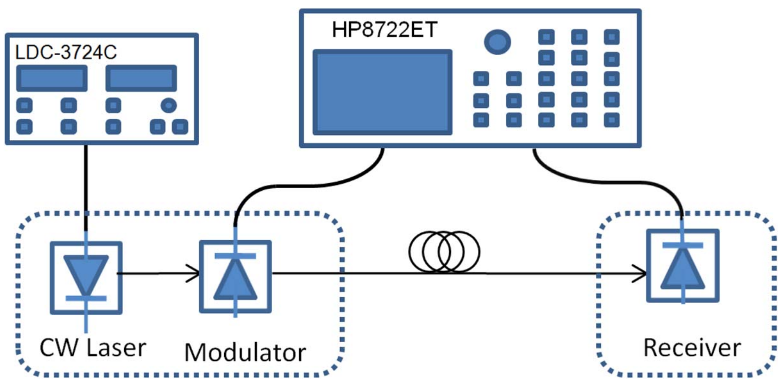

Fig. 5. Experimental setup.

and receiver. First, the EAM was used as modulator, and the photodetector was the receiver, a transmission curve $S_{21}{}^{\mathrm{I}}$ was measured. Then, the DFB laser was used as the transmitter, and the photodetector was still used as the receiver, another transmission curve $S_{21}{}^{\mathrm{II}}$ was measured. The third transmission curve $S_{21}{}^{\mathrm{III}}$ was obtained when the DFB laser was used as transmitter and the EAM was used as receiver. From (1), one can get that

$$S_{21}{}^{\mathrm{I}} = G_{\mathrm{EAM}} R_{\mathrm{PD}} \tag{5}$$

$$S_{21}{}^{\mathrm{II}} = G_{\mathrm{DFB}} R_{\mathrm{PD}} \tag{6}$$

$$S_{21}{}^{\mathrm{III}} = G_{\mathrm{DFB}} R_{\mathrm{EAM}}. \tag{7}$$

For our measurements, the data is measured as logarithm. Besides, the frequency responses of the devices calculated from the measurement are normalized frequency responses. So from (4)–(7), we can get

$$G_{\mathrm{DFB}} = \left(S_{21}{}^{\mathrm{II}} + S_{21}{}^{\mathrm{III}} - S_{21}{}^{\mathrm{I}} - \mathrm{C}\right)/2, \quad G_{EAM} = \left(S_{21}{}^{\mathrm{I}} + S_{21}{}^{\mathrm{III}} - S_{21}{}^{\mathrm{II}} + \mathrm{C}\right)/2, \quad \text{and}$$
$$R_{\mathrm{PD}} = \left(S_{21}{}^{\mathrm{I}} + S_{21}{}^{\mathrm{II}} - S_{21}{}^{\mathrm{III}} + \mathrm{C}\right)/2. \tag{8}$$

C is a constant and it will not influence the normalized frequency responses.

G_{DFB} and R_{PD} are the transmission parameters of the DFB laser and the photodetector, which can stand the frequency responses of the DFB laser and the photodetector. So the frequency responses of the three devices can be obtained, and the measured results are not limited by the

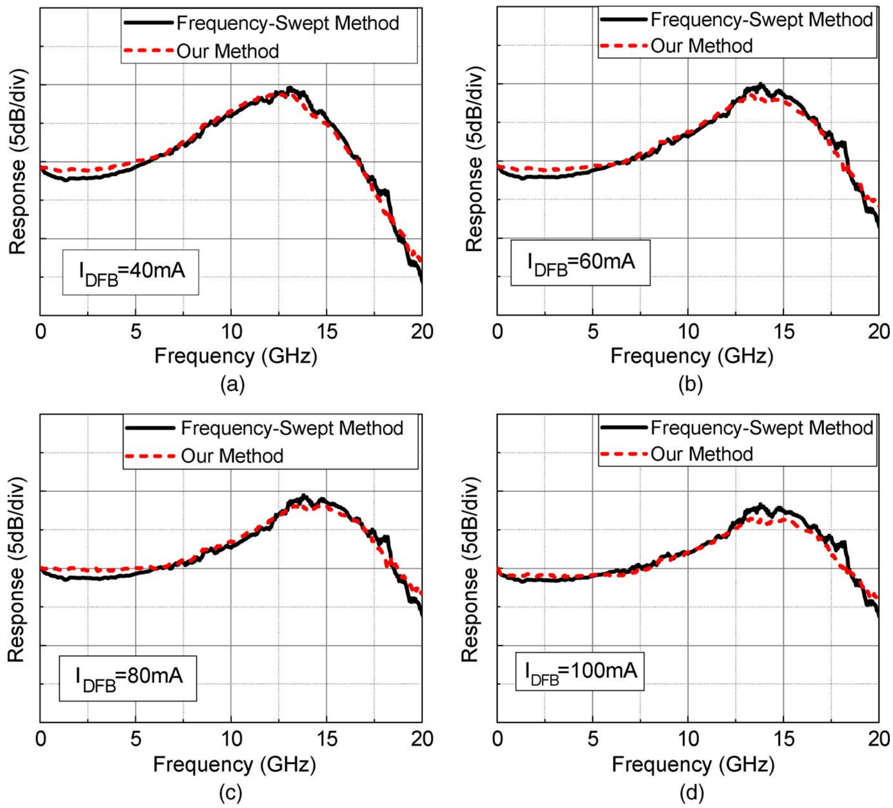

Fig. 6. Frequency responses of the DFB laser at different currents measured by two methods.

bandwidth of the devices. Besides, the frequency response of any device measured by this method is not influenced by other devices.

3. Experimental Setups and Results

The DFB laser was fabricated in our laboratory and its frequency response was affected by the bias current. The photodetector used in the measurements was a commercial device (HP 11982A) with the bandwidths from dc to 15 GHz. The EAM used in the measurement was also a commercial device with the bandwidths from dc to 10 GHz. A calibrated VNA (HP8722ET) was utilized to measure the frequency responses. For the frequency response of the DFB laser is current dependence, the DFB laser was measured with different bias currents. The bias voltage of the EAM was fixed at -0.7 V whenever it was used as modulator or receiver.

First, a transmission curve was measured between the EAM and the photodetector. Then, the DFB laser was used as the transmitter, the photodetector was used as the receiver, and a group of transmission curves were measured when the DFB laser was biased at different currents. Lastly, another group of transmission curves was measured while the EAM was used as the receiver instead of the photodetector. From (8), the normalized frequency responses of the DFB laser at different bias currents can be calculated from the measured transmission curves. For comparison, the frequency responses of the DFB laser at different bias currents were measured by the frequency-sweep method with another broadband photodetector with relatively flat response from dc to 20 GHz. The measurement results are shown in Fig. 6. From the results, one can clearly see that the differences between results measured by two methods (the red curves and the black curves) are quite small. One also can know that the differences between the results measured by the two methods did not change much as the bias currents change. The differences may be caused by the broadband photodetector for its frequency response was not absolute flat. Another reason is the uncertainty of the measurement system, which include the mismatches of the connectors and

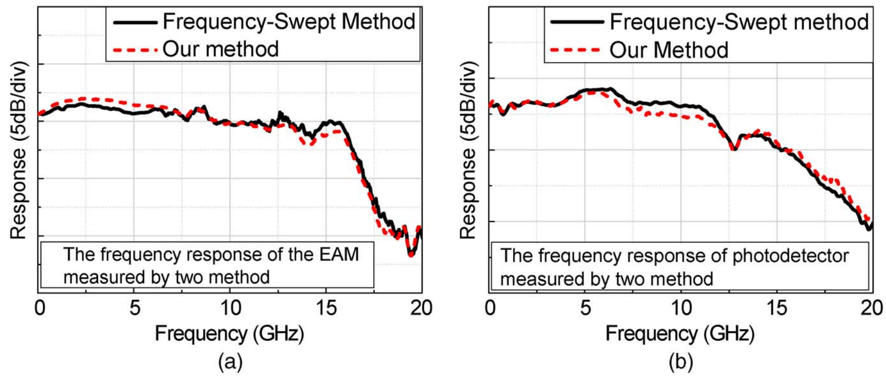

Fig. 7. Frequency responses of the EAM and the photodetector measured by two methods.

the measurement noises of the system. Besides, the results measured by the broadband devices have some sharp changes, which may be coursed by the calibration of the VNA or the connectors, but the results measured by our method can eliminate the influence of the calibration so the results measured by our method seemed smoother.

From (8), we also can get the frequency responses of the EAM and the photodetector from the measured transmission curves. We also measured the responses of the EAM and the photodetector by frequency-sweep method for contrast. The results are shown in Fig. 7. From the measurement results, one can see that the two transmission curves measured by different methods are also quite identical. We also measured the phase response of the EAM with this method, and the results show well coherence with magnitude response shown in Fig. 7(a).

4. Conclusion

We have developed a new method to measure the frequency responses of the broadband optoelectronic devices by the devices with relatively lower bandwidth. The method is based on the consistency of the frequency responses of the EAM used as modulator and used as receiver. The main advantages of the method are that the simple experimental setups and the unessential of broadband standard devices. We have measured the frequency responses of the DFB laser at different bias currents from dc to 20 GHz by an EAM with 10-GHz bandwidth and a photodetector with 15-GHz bandwidth. The results measured by the method are quite identical with the results measured by the frequency-sweep method with broadband devices but there still exist some differences. The root mean square difference of the results is less than 1 dB from dc to 20 GHz. The differences may be due to the measurement uncertainties. Besides, the results measured by the method are more creditable than the results measured by the broadband devices.

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