

# New Impedance Matching Scheme for 60 GHz Band Electro-Absorption Modulator Modules

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*ABSTRACT*—This letter proposes a new impedance matching scheme of a traveling wave electro-absorption modulator (TWEAM) module for a 60 GHz band radio-over-fiber (ROF) link. A microstrip band pass filter (BPF) was used to achieve impedance matching at the 60 GHz band, and termination resistance was carefully designed to obtain an input impedance close to 50  $\Omega$ . Also, a bias circuit for the device was designed in the module. The measured return loss and frequency response show that the modulator module observes the characteristics of a filter without the need of a further tuning process.

*Keywords*—TWEAM module, impedance matching, microstrip band pass filter, termination resistance.

## I. Introduction

Radio-over-fiber (ROF) link technology employs optical carriers that are intensity-modulated by microwave signals through optical modulators and transmitted or distributed to an optical receiver via optical fibers [1], [2]. Carrying a 60 GHz band on an ROF link for a broadband wireless access network takes advantage both of single-mode fiber and frequency characteristics of the 60 GHz frequency [2], [3]. An optical modulator as an electrical-to-optical converter is one of the key components in the ROF link. A traveling wave electro-absorption modulator (TWEAM) has the same merits as a conventional electro-absorption modulator (EAM) such as a small size, low driving voltage, large bandwidth, and easy

integration with other optical devices. In addition, it overcomes the bandwidth limitation of a conventional EAM. To make use of the high-speed properties of a TWEAM in a packaged module, an appropriate approach to the RF termination and the proper impedance matching scheme are necessary. Impedance matching at the operating frequency is necessary to increase RF link gain and reduce the noise figure of the link [1]. In previous works [4], [5], impedance matching was accomplished with a double stub design and laser trimming process. Since the tuning process is time-consuming and expensive, there is need for another design without a tuning process.

In this letter, we propose new impedance matching schemes to develop TWEAM modules optimized for a 60 GHz band ROF link. The impedance matching was obtained with a microstrip band pass filter (BPF) and a careful design of the input impedance with the termination resistance. With them, the fine-tuning process was eliminated. The bias for the modulator was implemented in the module. The return loss and frequency response of the ROF link with the modulator were measured.

## II. Design and Fabrication of Device and Module

The EAM device has a multiple quantum well structure and coplanar traveling wave electrode. The electrical insertion loss was less than 3 dB, and the return loss was larger than  $-12$  dB in the entire frequency range of up to 65 GHz [6], [7]. The characteristic impedance of the active region of the device was calculated as about 30  $\Omega$ . Figure 1 shows the structure of the module. The device was parallel connected with the termination resistor. The inductor was a bias line for the device and was between the device and the filter. The filter plays the role of a capacitor of the bias circuit and the impedance

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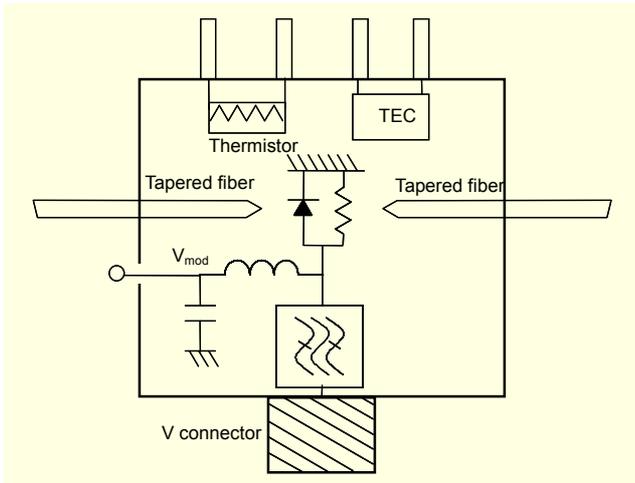


Fig. 1. Structure of TWEAM module

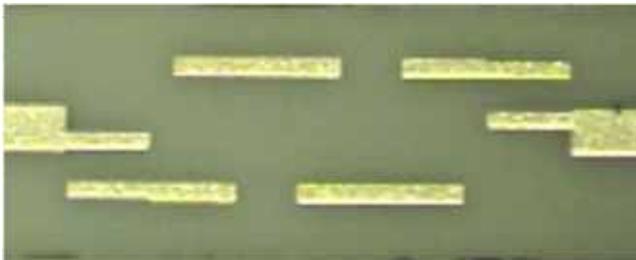


Fig. 2. Photograph of microstrip BPF

matching circuit. The tapered fibers were used for the optical alignment with the device. A thermoelectric cooler and thermistor were used for the temperature control of the module. Interconnection between the components was a wedge bonding with coplanar configuration.

Figure 2 shows a photograph of the fabricated microstrip BPF, which is composed of four  $\lambda/2$  microstrip line resonators. Its size was  $1.4 \times 4.4 \text{ mm}^2$ . The presented BPF topology is based on two parallel transmission lines with image arbitrary admittance as given by D. Ahn [8], and on a combination of parallel-coupled line with open-coupled line as given by E. Hanna [9] and Isable Ferrer [10]. We simulated the BPF using High-Frequency Structure Simulator (HFSS), which has a microstrip BPF in the shielding waveguide. Accordingly, the microstrip BPF has two transmission zeros by combining the parallel coupling and end gap coupling: one is due to end coupling and the other is due to the shielding waveguide. A detailed description of the design and the performance of the filter were reported in [11].

Figure 3 shows the measured characteristics of the designed microstrip BPF with the network analyzer. The insertion loss and return loss at 60 GHz were 5.24 dB and 18.86 dB, respectively. A sharp cutoff performance was obtained. Since the RF and LO frequencies of the ROF link were 60 GHz and

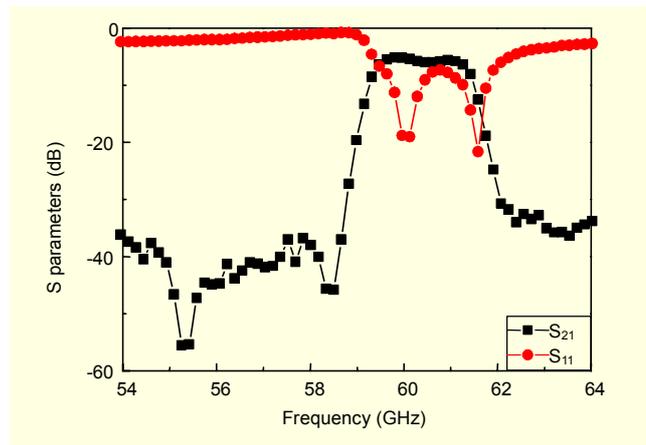


Fig. 3. Measured frequency response of a microstrip BPF.

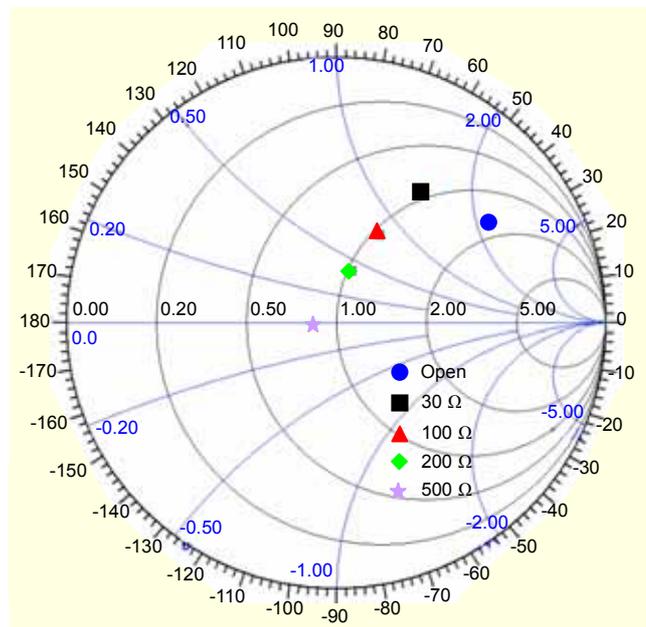


Fig. 4. Simulated input impedance variations at 60 GHz with the termination resistance.

57.6 GHz, respectively, the RF signal needed to be in the passband of the filter and the LO signal in the stop band. From the measured results, it was concluded that the filter could be used in the module.

Since the termination resistance affects the input impedance seen from the filter, which in turn has an effect on the performance of the filter, its value should be carefully designed. In addition, if the input impedance can be designed close to 50  $\Omega$  with the termination resistance, then the additional process of fine-tuning is not necessary. The measured S parameters were combined with the simulated termination resistance, the interconnection, and the microstrip line in front of the filter using HFSS. Since the dependence of the S parameters of the EAM device on the bias was not strong near the 60 GHz band,

the S parameters without the bias were used. Figure 4 shows the simulated input impedance variations at 60 GHz with the termination resistance. From the results, 500  $\Omega$  was adopted as the termination resistance to achieve the largest return loss.

### III. Performance of the Module

After packaging a modulator module, the return loss was measured with a network analyzer. To measure the frequency response of the link with the modulator module, a simple RF/optical link was formed back-to-back using the modulator module and a commercial receiver connected with an optical fiber. The frequency response was also measured with the network analyzer. The RF input power and the optical input power to the modulator were  $-2$  dBm and 5 dBm, respectively, and the optical input power to the receiver was adjusted to 0 dBm with an erbium-doped fiber amplifier and an optical attenuator.

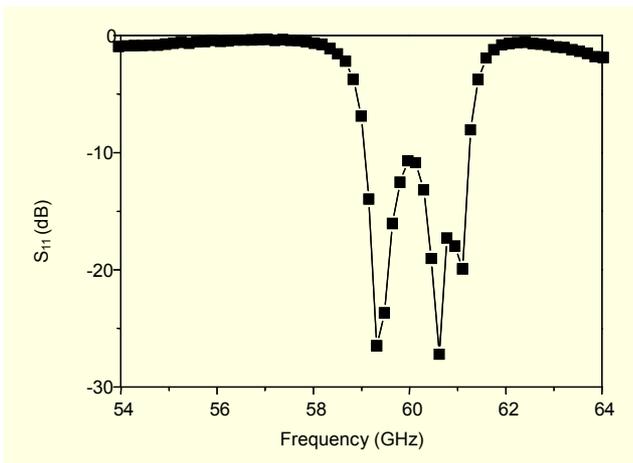


Fig. 5. Measured return loss of a TWEAM module

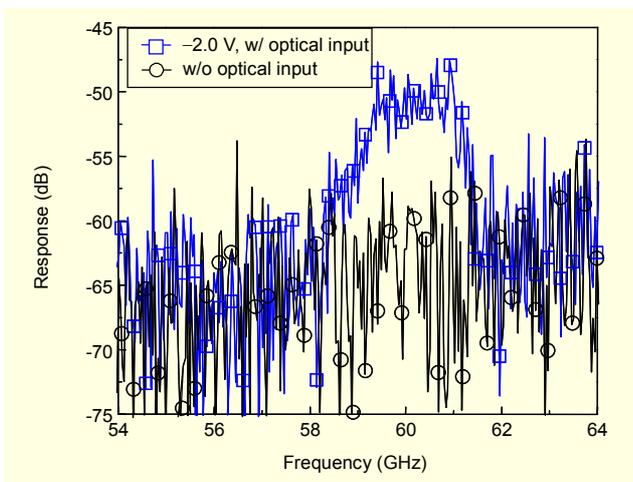


Fig. 6. Measured frequency response of a TWEAM module

Figure 5 shows the measured return loss of a modulator module. The result shows the characteristics of the filter, which means the input impedance seen from the filter is close to 50  $\Omega$  as predicted with the simulation. The module bandwidth of an  $S_{11}$  less than  $-10$  dB is about 2 GHz, which is the same range of the previously-developed module. As in the filter, the LO frequency is out of the passband so that the filter can play a role in the band selection as well as in the image rejection.

Figure 6 shows the measured frequency response of the link. Since the optical-to-electrical response of the receiver was linear with the frequency, the response can be considered to represent the characteristics of the modulator module. From the frequency response without optical input to the link, the noise floors of the link and the network analyzer were observed. As the bias of the modulator and the laser was applied, the response at 60 GHz increased around 12 dB. The increased frequency response came from the fact that the RF gain of the ROF link depends on the slope efficiency of the modulator, and the slope efficiency of the modulator has the maximum value at a bias of around  $-2.0$  V [12]. The increase of the frequency response with bias indicated that the bias line for the modulator worked well, and the new impedance matching scheme was proper for the ROF link. The increase frequency response near 60 GHz leads to the increase in the RF gain of the ROF link.

### IV. Conclusion

A new impedance matching scheme was proposed and validated. The module with microstrip BPF and an appropriate termination resistance showed a return loss of larger than 10 dB near 60 GHz without the fine-tuning process. Also, an internal bias circuit for the EAM device was proved to be applicable in the module.

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