Combined digital/wireless link over the Multi-Mode Fiber with a Vertical Cavity Surface Emitting Laser

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Abstract – **In this paper, we present the simultaneous transmission of the baseband digital signal and wireless LAN signal over a multi-mode fiber using a VCSEL. For this hybrid optical link, a new type of combiner is used. For the overall link simulation, a rate-equation based VCSEL model is implemented with circuit components, which describe the high-speed modulation characteristic as well as the thermal effect on the L-I characteristic. The overall optical link is implemented on a Multi-Layer Organic board. An OC-48 baseband data stream and wireless LAN (802.11a) signal at 5.8GHz are applied to the link and successfully transmitted. To the best knowledge of the authors, this is the first demonstration of VCSEL technology for a hybrid optical link.**

I. INTRODUCTION

With the explosion of the information age and the increased demand for data services, such as the Internet, e-commerce, telecommuting and home-office expansion, the need for various wire/wireless/fiber-optic data communication systems has arrived. For short-reach applications, current systems consist of copper cables and multi-mode fibers (MMF), but for future bandwidth expansion, MMFs will have to be used. These fibers are not used to their maximum potential, resulting in inefficient usage of the fiber-optic cables. One solution to this efficiency problem is to employ a hybrid approach, which can seamlessly integrate multi-band signals [1]. A promising system is the very short reach (VSR) hybrid digital/RF fiber optic link system, which transmits baseband ethernet signals and RF signals for GSM/PCS//IMT-2000/WLAN data traffic simultaneously via a fiber-optic link. In this paper, we present a hybrid optical link with direct modulation of the VCSEL. A new type of combiner is used for the implementation of the link.

A Vertical Cavity Surface Emitting Laser (VCSEL) is a good candidate for this hybrid optical link due to its small active region that results in a low threshold current. In addition, a VCSEL also provides a higher modulation bandwidth compared to other light sources for an equivalent output power [2]. The high-speed modulation characteristic of the VCSEL has been previously modeled with circuit based elements [3] and improved to 2 port model in this work.

The hybrid optical link also requires a combiner, which can send the baseband signal and wireless signal with low interference with each other. It is also necessary for the combiner to have a broad bandwidth. The conventional Wilkinson power combiner is not suitable for broadband applications since it needs additional sections and increases the overall insertion loss and circuit complexity [4]. Also the conventional combiner will not reduce the interference between the two different signals when it is used for simultaneous transmission. For the reason, to reduce the interference, a new type of combiner has been proposed for this hybrid optical link application [5]. This combiner also achieves the broad bandwidth necessary for the hybrid optical link.

For this VSR application, direct modulation of the VCSEL is used, as it can implement the hybrid link utilizing a simple architecture at a low cost. However, for the optimization of the overall optical link performance, a link simulation is required with the hybrid combiner being optimized with the VCSEL model.

The overall link performance is optimized, via the link simulation with the combiner and the developed VCSEL model. For the practical implementation of the hybrid optical link, we adopt the OC-48 baseband signal and 802.11a wireless LAN signal. The hybrid optical link is tested with 100m of MMF. Due to modal dispersion effects, future development of an adaptive equalizer will allow for transmission above 100m. Detailed explanation of the hybrid combiner performance, the VCSEL model, and the overall link simulation are presented in this paper.

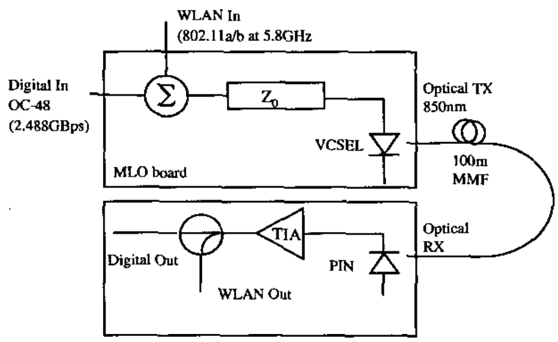

Fig. 1. Basic block diagram of the hybrid optical link

II. LINK CONFIGURATION

The overall hybrid optical link is composed of an improved broadband combiner, a VCSEL with 10GHz modulation bandwidth, a photoreceiver, and a splitter that separates the baseband signal from the WLAN signal in the receiver. The basic block diagram of the overall hybrid optical link is shown in Fig 1. The baseband digital signal (OC-48) and the WLAN signal (802.11a), which is at 5.8GHz, is sent through the combiner, which is implemented on a Multi-Layer Organic (MLO) board. The combined baseband and WLAN signal is transmitted over a 100m MMF with 62.5μm core size. The signals are transmitted with a 10GHz VCSEL, which is mounted on the MLO board and wire-bonded to the combiner.

A. Hybrid Combiner

The combiner was designed with modification to the conventional coupled line coupler, so as to couple the wireless signal and transmit, while sending the baseband signal reducing the interference between those two signals. The two signals that are to be combined are a wireless signal at 5.8GHz (802.11a) and the OC-48 data stream. This multi-layer structure is composed of three parts: a step impedance low pass filter, an embedded microstrip line, and a vertical coupling structure, which is modified from the coupled line coupler [5]. Since the combiner has a low pass filter characteristic, the interference of the baseband data signal to the RF range can be reduced. Also, the coupling frequency range of the combiner can be adjusted by changing the length of the vertical coupling structure. The RF range can be easily changed via simple design modifications. As a result, we can combine the two different frequency range signals over several GHz without distortion around DC.

The combiner is fabricated via the MLO process developed at The Georgia Institute of Technology. Fig 2 shows the measurement result of the combiner. Port 1 is used for the baseband signal input, port 2 is used for the WLAN signal, and port 3 is used as the output of the combiner. The insertion loss from port 2 to the output of the combiner was measured to be 1.4 dB. The isolation between port 1 and port 2 of the combiner is greater than 10.6 dB for the baseband signal and 38 dB for the WLAN signal at 5.8GHz. These results satisfy the requirement for the hybrid optical link.

B. VCSEL Model and Link Simulation

For the perspective of the optoelectronic circuit design, the VCSEL model is essential to optimize the driver circuitry. Contemporary circuit designs use a simple RC parallel lumped element VCSEL model. However, for the overall system level simulation and prediction of the modulated optical signal waveform, the 2-port model of the VCSEL is necessary.

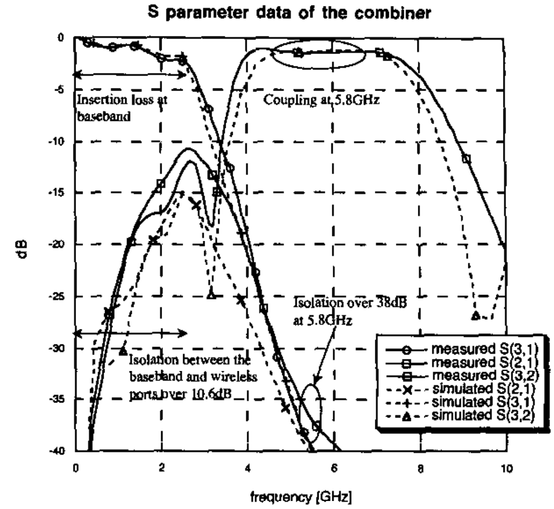

Fig. 2. Measurement and calculated result of the combiner

Here we developed the VCSEL model, which can describe the optical power intensity vs. the injection current (L-I) including thermal roll-over in optical power, input impedance and the forward transmission characteristic of the VCSEL over high frequency.

For the input impedance characteristic of the VCSEL, we used the diode equation with series resistance, which accounts for the differential resistance of the VCSEL over different bias current. Also, accounting for the parallel junction capacitance and series inductance, we successfully modeled the small signal input impedance characteristic of the VCSEL. Fig 3 shows the input impedance of the VCSEL model with measurement result.

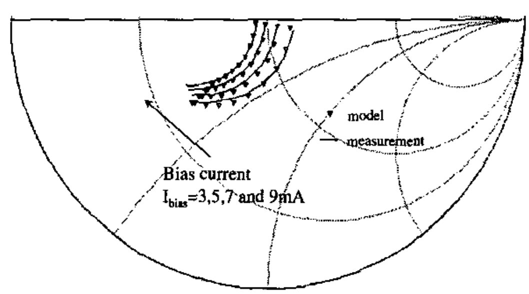

Fig. 3. Input impedance characteristic of the VCSEL model with measurement result.

The offset current is introduced in the rate-equation to account for the thermal effect on the L-I characteristic [6]. The circuit based implementation of the rate-equation describes the high speed forward transmission characteristic of the VCSEL as well. By adding the I_{off} (offset current), the rate equation is modified to

$$\frac{dN}{dt} = \frac{\eta(I - I_{off}(T))}{q} - \frac{N}{\tau_n} - \frac{G_o(N - N_o)S}{1 + \varepsilon S}$$

$$\frac{dS}{dt} = -\frac{S}{\tau_p} + \frac{\beta N}{\tau_n} + \frac{G_o(N - N_o)S}{1 + \varepsilon S}$$

where S is the photon number, N is carrier number, τ_n and τ_p are carrier recombination life time and photon life time each. β is spontaneous coupling coefficient, ε is gain compression factor, N_o is carrier transparency number, and G_o is the optical gain coefficient. Fig 4 and Fig 5 shows the L-I curve and forward transmission characteristic of the VCSEL model and measurement result.

The overall link is simulated with the circuit based VCSEL model and combiner model. Time domain link simulation shows the eye diagram and overall spectrum of the optical signal. As the model describes the non-linear L-I characteristic, the mixing effect between baseband and WLAN signal can be described. The overall link simulation result is shown on Fig 6.

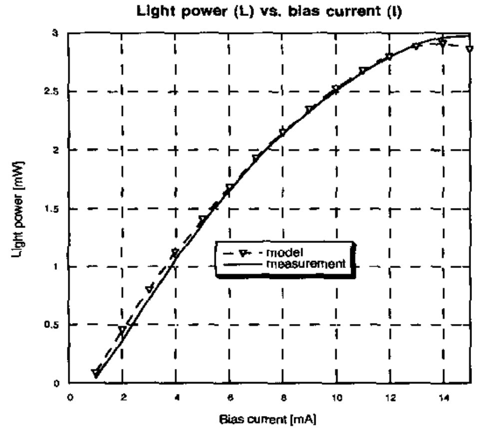

Fig. 4. Non-linear L-I characteristic of the VCSEL

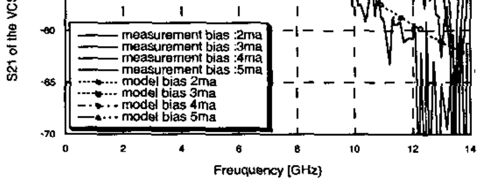

Fig. 5. Forward transmission characteristic of the VCSEL

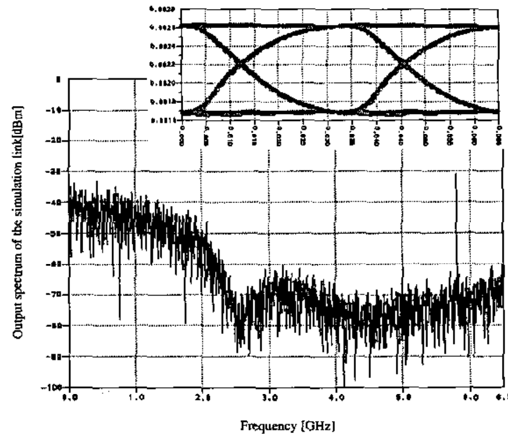

Fig. 6. Eye diagram and spectrum of the overall link simulation

III. MEASUREMENT RESULT AND DISCUSSION

For the overall link measurement, we incorporated an OC-48 bit stream and a 802.11a WLAN signal and applied them to the hybrid link transmitter. A 100m MMF with 62.5μm core size is directly coupled to the VCSEL. The combined signal is detected at the photoreceiver and is fed through the splitter on the receiver side. The picture of the hybrid link is shown on Fig 7. The entire link spectrum is shown in Fig 8. When the two signals are transmitted simultaneously, the baseband data signal is mixed with the wireless carrier signal due to the non-linear L-I characteristic of the VCSEL. As a result, there is a small amount of frequency re-growth on the RF spectrum. However, by adjusting the bias of the VCSEL and baseband signal power level, the frequency re-growth can be minimized. Also the eye diagram of the baseband signal is shown in Fig 9. The modal dispersion of the MMF makes the eye opening of the received signal more disperse. In terms of the modal dispersion bandwidth of the MMF, 160MHz.km and 500MHz.km at a wavelength of 850nm and 1300nm, respectively, is specified. However, recent research has shown that the passband beyond the modal dispersion bandwidth of the MMF is usable for transmission of additional data [7]. In this system, the wireless signal at 5.8GHz is successfully transmitted beyond the modal dispersion bandwidth of the MMF via the passband region of the MMF.

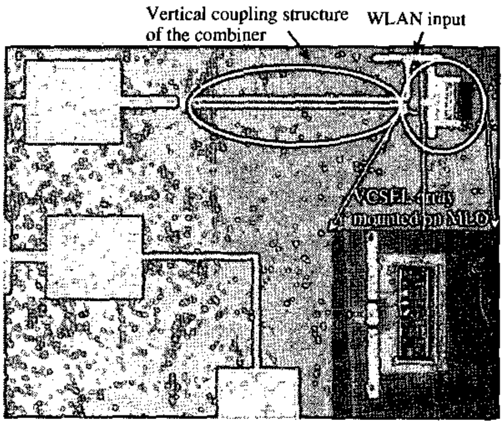

Fig. 7. Picture of the hybrid optical link

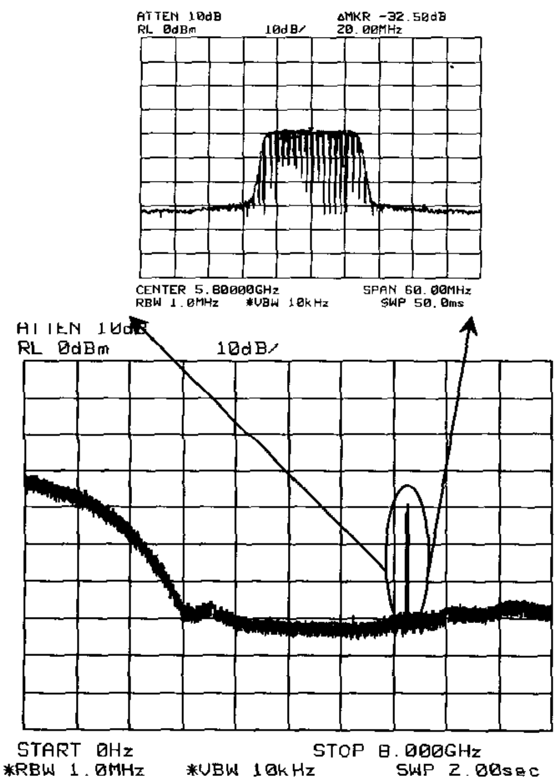

Fig. 8. Measurement results of the received signal spectrum of WLAN (802.11a), OC-48 data stream and the enlarged view of the WLAN signal.

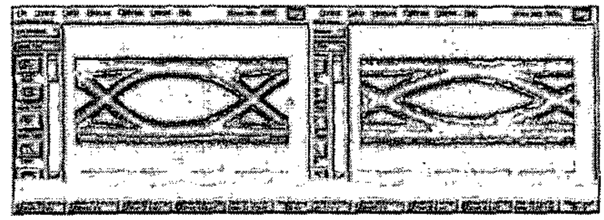

Fig. 9. Eye diagram of the OC-48 data stream before the MMF and after the MMF.

IV. CONCLUSION

Hybrid optical link is designed via the novel combiner with direct modulation of the VCSEL. The overall link measurement and model based link simulation has been shown. The OC-48 data stream at baseband and WLAN (802.11a) signal at 5.8GHz is successfully transmitted and received over the 100m MMF. Overall link is implemented on the MLO board. This is the first demonstration of the VCSEL technology for hybrid optical link.

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