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Link Length Analysis of a Radio-on-Fiber System for a Cube Satellite Earth Station

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Abstract: A microwave link in an earth station for a small cube satellite has become a big issue especially when higher frequencies are used. This paper proposes use of radio-on-fiber link and discusses link length limitation from a standpoint of chromatic dispersion. Simulation results show that the maximum link length is 7 km even at a frequency of 13 GHz with the proposed system. In addition, it is shown that the maximum link length can be extended more by varying a chirp parameter of an electro-absorption modulator in the system.

Keywords: **cube satellite, radio-on-fiber, chromatic dispersion, earth station, EML.**

I. BACKGROUND

A lot of small cube satellites are functioning on space orbits. Some of them carry two or more transmitters and receivers to achieve various missions; hence, earth stations are equipped with more radio systems and their internal links between antennas and a control site become more complex. Taking Kagoshima Satellite 2 or KSAT2 as an example of the small cube satellite, it used 0.4 and 2.0 GHz for uplink and 2.2 and 13 GHz for downlink. A cube style KSAT2 is as small as 10 cm, as shown in Fig. 1.

Fig. 1: Photograph of KSAT2, developed by a consortium with Kagoshima University. A main body at the bottom is a 10-cm cube. The outers are solar cell panels (both sides) and a pantograph (top) for stabilization.

A radio-on-fiber (RoF) link is one of the powerful solutions to reduce link loss, to minimize phase error, and to simplify the system. We have already analyzed RoF performances theoretically and have employed such a system in the control site. A maximum link length was one of the unknown characteristics to be resolved. The link length is limited by two factors, power loss and chromatic dispersion (CD) in an optical fiber. Power loss

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can be easily compensated by an optical amplifier although CD remains as the last factor. In this paper, we analyze link length limitation that occurs from CD. A RoF transmitter model is proposed and numerical analyses are presented.

II. ANALYSIS METHODS

A. Proposed Model

The proposed RoF transmitter employs a single electro-absorption modulator integrated laser diode (EML) as a laser source that carries two or more radio-frequency carriers simultaneously. KSAT2 used four segments in P, S, and Ku bands. In the EML, a laser diode (LD) is usually biased with DC current while an electro-absorption modulator (EAM) accepts high-bit-rate data or high-frequency RF signal. Our method is somewhat different; Lower- and higher-frequency RF signals are fed into the LD and EAM, respectively, as shown in Fig. 2. That is, only the single laser device realizes frequency division multiplexed RoF transmitter. When we apply the proposed model to the downlink in our earth station, the higher frequency signal, 13 GHz or Ku band, is input to EAM and the lower frequency signal, 2.2 GHz or S band, to DFB-LD. The multiplexed laser with the RF subcarriers is incident into an opto-electronic (O/E) converter through an optical fiber.

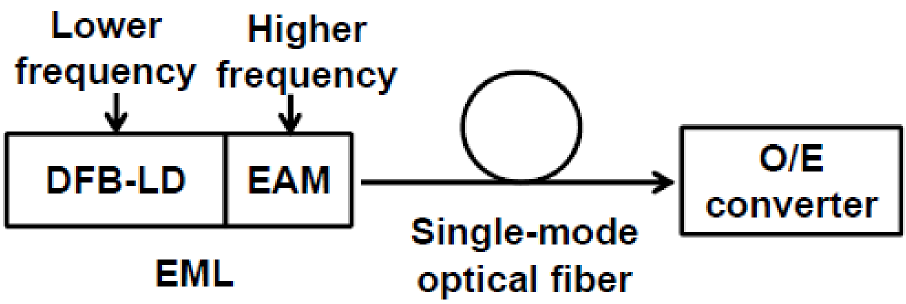

Fig. 2: Proposed model employing an EML as an E/O converter in a RoF link system. DFB-LD stands for distributed feedback laser diode. The DC current and voltage sources are omitted to avoid complexity.

B. Simulation Method

As the RF frequency becomes higher, CD that limits the link length and/or RF carrier frequency becomes noticeable. We analyze these limitations by simulation as follows. Figure 3 shows light spectrum of our model. As the simplest model, Eq. (1) considers only the first-order subcarrier or side modes while the actual expression is more complicated. ii) The current-laser output curve is fit with a polynomial expression based on experimental results. The voltage-transmission or absorption curve is fit with a polynomial equation as well with the experimental results shown in Fig. 4. iii) The spectral intensity is the highest at the free-running LD frequency while it follows even number of side lobes, corresponding to the RF signals and their harmonics. iv) Polarization mode dispersion is not considered. Finally, we perform simulation under these assumptions bellow.

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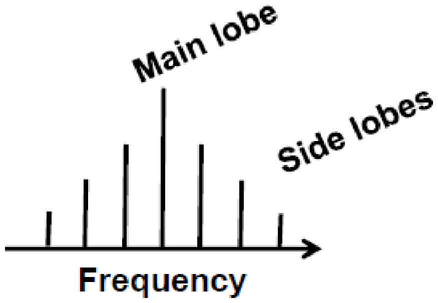

Fig. 3: Light spectrum of our model. The number of spectral lines increases as the linearity of EML degrades.

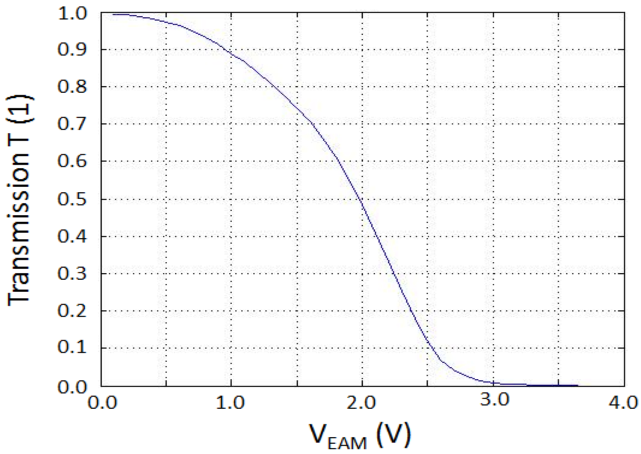

Fig. 4: Transmission dependence on the applied voltage to the electro-absorption modulator, V_{EAM}

Our calculation method mentioned above is a general one; however, we show simulation results only for the 2 and 13 GHz here, focusing on our interest. If the modulation curves for LD and EAM are linear, the +/-first-order subcarrier is the only signal component. Both of the characteristics are nonlinear actually, though. We fit these curves with the sixth-order polynomial expressions and, then, we can consider up to the +/-sixth subcarriers' harmonics. Here are some of other important conditions and parameters. The LD wavelength is 1.55 μm and the optical fiber is a standard single mode fiber (SMF). The multiplexed frequencies are 2 and 13 GHz in the S and Ku band, respectively. The simulation was carried out with MATLAB and a PC.

III. SIMULATION RESULTS

Simulation results are presented in Section III. Chromatic dispersion-induced penalty (CDP) dependence on the SMF length is shown in Fig. 5. CDP at 2 GHz increases as the SMF becomes longer while the highest CDP, which is obtained at 100 km, is calculated as only 0.12 dB. As for the frequency of 13 GHz, a CDP dependence on the fiber length exhibits a periodic curve with a period of 45 km and the first signal vanishing point is 22.5 km. Another calculation is maximum SMF length dependence on the frequency, shown in Fig. 6, where the maximum length is defined at the 1-dB penalty. The maximum lengths get shorter as the frequency becomes higher, and they are approximately 280 and 7 km for 2 and 13 GHz, respectively.

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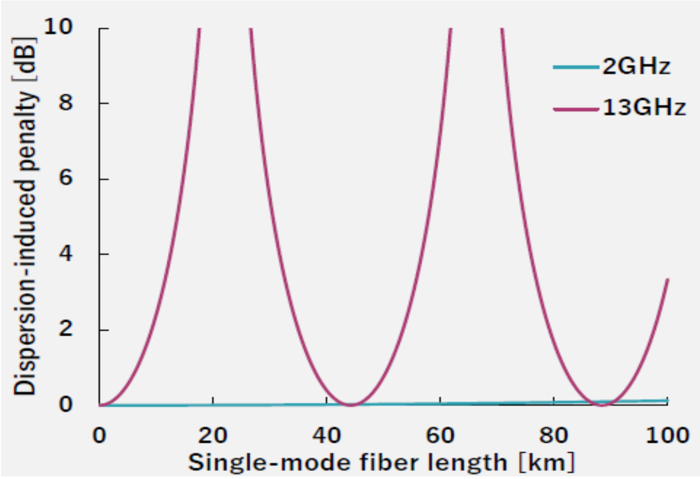

Fig. 5: Chromatic dispersion penalty dependence on the SMF link length

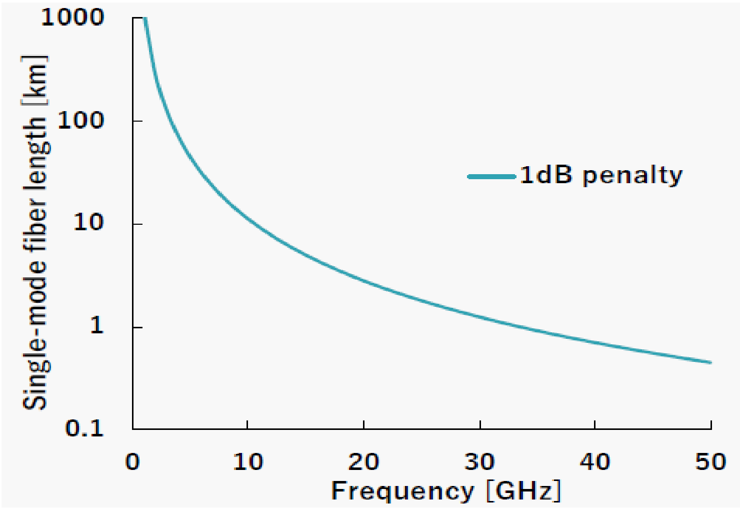

Fig. 6: Link length limit dependence on the RF frequency

After the simplest simulations mentioned above, we made more simulations, considering the higher order modes. The EML characteristics are non-linear, as shown in Fig. 4. A new equation is derived as

$$p = \left\{ \frac{\sum_{i=1}^{\frac{n-3}{2}} \sqrt{r_i r_{i+1}} \cos\left(\frac{(n-2i)\pi\lambda^2 D f_{rf}{}^2 L}{c}\right) + \sqrt{r_{\frac{n-1}{2}}} \cos\frac{\pi\lambda^2 D f_{rf}{}^2 L}{c}}{\sum_{i=1}^{\frac{n-3}{2}} \sqrt{r_i r_{i+1}} + \sqrt{r_{\frac{n-1}{2}}}} \right\}^2 \tag{2}$$

Where r_i is a suppression factor between the adjacent modes and other symbols are the same with the symbols in eq. (1). Figure 7 shows CDP dependence on the number of modes for the link length L of 5, 8, and 10 km under the assumption that a modulation index m is 0.1. As the number of modes increases from 3 to 5, CDP increases slightly although the degradation is not serious for the shorter link length. In addition, CDP increases as the link becomes longer. CDP dependence on the modulation index is another key issue. In the CDP in dB vs. m curves in Fig. 8, the logarithmic plot of CDP is proportional to the modulation index and to the link length.

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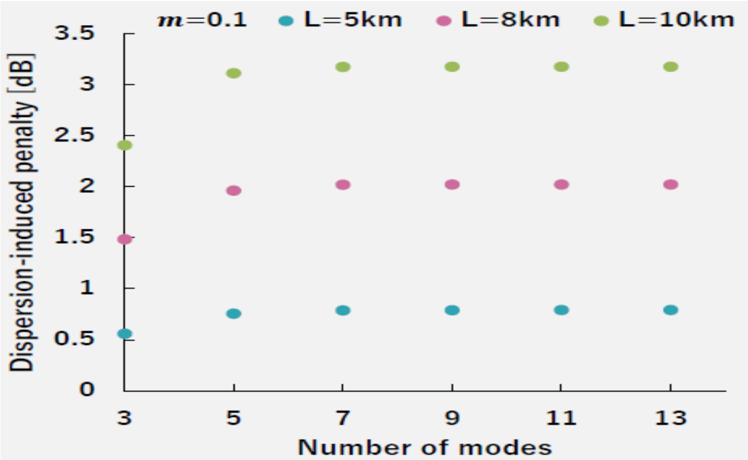

Fig. 7: Chromatic dispersion penalty dependence on the number of modes

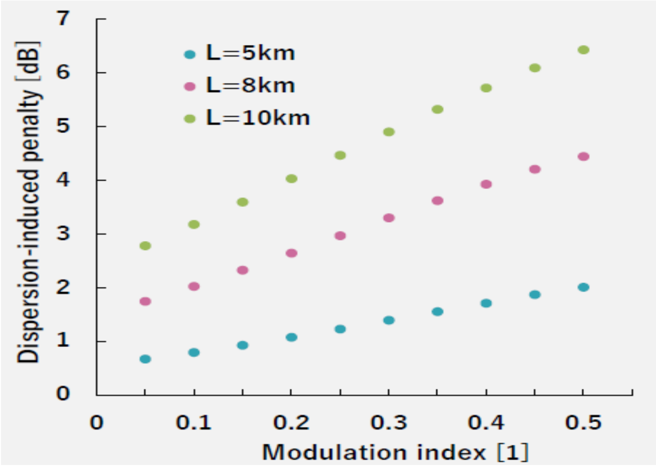

Fig. 8: Chromatic dispersion penalty dependence on modulation index

IV. DISCUSSION

We have already understood that the RoF link is powerful to establish a microwave earth station of cube satellite station. Even at 13 GHz, the link length can be 7 km, which satisfies most of the station requirements. In spite of these results, we will further lengthen the link. Note that a chirp parameter of the optical modulators is quite important when we discuss CD. Figure 9 shows CDP dependence on the SMF length with some chirp parameters, α. At this satellite application, CDP is improved when the chirp parameter is negative. The maximum lengths are approximately 7, 10, and 12 km for the chirp parameters of 0, -1, and -2. It is shown that the link length can be further improved if we can control the chirp parameter.

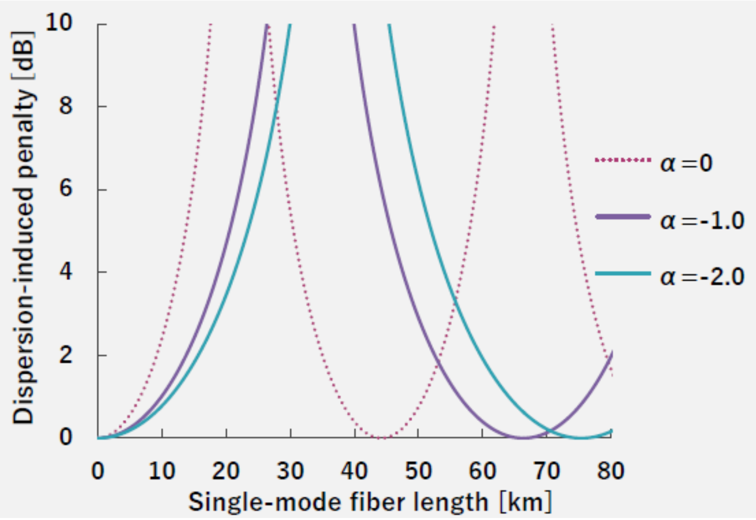

Fig. 9: Chromatic dispersion penalty dependence on the link length with a chirp parameter.

V. CONCLUSION

In conclusion, we proposed a RoF link model for a cube satellite earth station, which handles some frequency bands including the Ku band simultaneously. The simulation analyses have been carried out to examine how long the link can be. Our results show that our model can be applied to the link with the lengths of up to 280 and 7 km for the S and Ku bands, respectively. An earth station in a university usually has only a-few-km link so that we can employ our RoF link model in its earth station. Moreover, it is shown that the chirp parameter is one of the important factors and that the introduction of negative parameter can lengthen the link more. Analysis of other dispersion such as polarization mode dispersion should be the next study of ours.

VI. ACKNOWLEDGMENT

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