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Fiber Chromatic Dispersion Effects of Broadband mm-Wave Subcarrier Optical Signals and Its Elimination

12.1 Effects on Multichannel Digital Millimeter-Wave Transmission

The millimeter-wave (mm-wave) frequency band offers the free-space bandwidth necessary for future broadband wireless communications services. A high-capacity broadband wireless network can be the quickest and most cost-effective method of delivering services to a large number of customers in a dense environment. Millimeter-wave optical fiber links can effectively distribute mm-wave signals from a central office to remote antennas located at suitable vantage points for line-of-sight interconnection to other nodes of the network. As described in [112], these fiber links offer simplification of base stations and centralized control and stabilization of mm-wave carrier signals for conformity to FCC standards. Even though it is expected that this type of fiber systems will take advantage of legacy metropolitan fiber cable plant infrastructure at the dispersion minimum of 1,300 nm. The low fiber loss and availability of optical amplifiers at 1,550 nm can extend the central office coverage over a much larger service area than 1,300 nm links. Therefore it is still important to understand how dispersion in a fiber link can affect the transmitted information on mm-wave subcarriers. The effects of fiber chromatic dispersion on a single carrier have been examined in [113, 114]. A two-tone analysis was done in [115]. Because future broadband high-capacity services will have many digital channels, a multiple-channel analysis is needed. A CATV band simulation was reported in [116]. This chapter explores the effects of fiber chromatic dispersion on broadband 18 channel mm-wave subcarrier multiplexed (SCM) transmission. Instead of studying a particular digital QAM format, the study here concentrates on the fundamental limits due to chromatic dispersion-induced carrier degradation and intermodulation distortion at mm-wave frequencies. Transmission of multichannel mm-wave signals over single-mode fiber will also be limited by the optical link noise contributions from the receiver, laser RIN, and fiber amplifiers.
A 1,550 nm externally modulated fiber system will be studied because

1. High frequency external optical modulators are available both commercially and in the laboratory (for more discussions, see Appendix C);
2. Chirping is minimal for these optical transmitter sources, the transmitter output is thus a pure amplitude modulation with very little phase modulation.

The system was modeled using the Signal Processing Worksystem simulation tool [118]. The model block diagram is shown in Fig. 12.1. A high-speed external optical modulator modulates a narrow linewidth (DFB) 1,550 nm optical source. The finite laser linewidth can lead to a negligible mm-wave carrier power degradation for typical line widths [119]. The modulator is modeled as linearized over the mm-wave band of interest (e.g., 27.5–28.5 GHz). External modulators have been demonstrated in this frequency range [120]. There are various methods for modulator linearization [121]. The electrical input to the optical modulator is the sum of 18 millimeter-wave channels.

The optical fiber is modeled as a unity amplitude, linear group delay filter. Standard single-mode fiber is used with a dispersion parameter of 18 ps km$^{-1}$ nm$^{-1}$ at 1,550 nm. Nonlinear fiber effects described in [122] are neglected in this simulation. A magnitude squared function models a high-speed detector and a FFT function gives the detector output spectrum.

A detected single subcarrier will experience a signal power variation with fiber transmission distance due to chromatic dispersion [113,114]. This is because the single subcarrier is transmitted through the fiber as optical sidebands on the optical carrier. The sidebands experience phase changes due to fiber chromatic dispersion so that the detected signal is effectively a sum of two signals with a phase difference that is a function of the fiber length. It can be shown that for small modulation depths the detected signal power of the single subcarrier is approximately proportional to [114]

$$P = \cos^2 \left( \frac{\pi D\lambda^2 L f^2}{c} \right)$$

(12.1)