
**CMR5 2:45 pm**

Subcarrier modulation for transmission of 1-Gb/s channels over 500 m of 62.5-μm multimode fiber

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The growing demand for high-speed interconnects for Local Area Network (LAN) applications makes it interesting to study alternative modulation formats to increase the transmission capacity of widely used 62.5-μm multimode fiber (MMF). For example, the available bandwidth for baseband modulation at 850 nm limits Gigabit Fiberlink to distances of 275 m. Subcarrier Multiplexing (SCM) is an attractive technique for increasing the data capacity using existing multimode fiber links. Although SCM has been widely reported for providing broadcast services to cable TV subscribers, SCM transmission over MMF was first achieved by Raddatz et al. in 1998. Since then the transmission of 1-Gb/s 27-1 PRBS over 1-km MMF using a single subcarrier at 2.5 GHz has been reported. In this paper we report the use of two different subcarriers at frequencies up to 5.5 GHz each transmitting 1 Gb/s over 500 m of MMF.

Using conventional NRZ modulation a data channel is limited in bandwidth by the modal dispersion inherent in multimode fiber. Subcarrier multiplexing presents a way to overcome this limitation by using the regions of fairly flat response at frequencies beyond the fiber's 3-dB frequency. By transmitting several narrowband channels in the passband regions, rather than a single broadband channel, a significant increase in the data transmission capacity of MMF is possible.

The fiber used in the experiments is a 500-m length of 62.5-μm core diameter MMF, which exhibits a near "worst-case" modal bandwidth of 200 MHz/km (λ = 850 nm). Figure 1 shows the frequency response of the fiber at 850 nm and indicates areas of flat response in the passband at around 3 and 5.5 GHz.

**CMR5 Fig. 1.** RF frequency response of 500-m multimode fiber showing a 3-dB bandwidth of 409 MHz and regions of relatively flat response located at 3 GHz and 5.5 GHz (wavelength 850 nm).

Furthermore amplified to allow bit-error-rate (BER) monitoring. The eye diagrams after transmission over 500 m of the "worst-case" fiber are shown in Fig. 3. Using conventional baseband transmission 800 Mb/s is the maximum data rate obtainable for a BER < 10^-9. However, at subcarrier frequencies of 3 GHz and 5.5 GHz open eye diagrams are obtained at 1 Gb/s and error-free operation is achieved in each case.

SCM transmission represents a significant increase in the link capacity over conventional baseband techniques. By transmitting the two subcarrier channels simultaneously alongside the baseband signal, an aggregate bit rate of 2.8 Gb/s is possible. This represents an improvement of 250% in transmission performance over the baseband case, which is the highest SCM transmission over MMF yet achieved. Details of this simultaneous transmission will be given at the conference.


**CMR6 2:45 pm**

A "tandem" single sideband fiber-optic system using a dual-electrode Mach-Zehnder modulator

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Optical single sideband (SSB) modulation has received great interest as a way to reduce the dispersion penalty of analog fiber-optic systems. In this paper, we propose and demonstrate a "tandem" single sideband fiber-optic link, which uses a dual-electrode Mach-Zehnder (M–Z) modulator to place different information in each of the two sidebands, thus doubling the bandwidth efficiency.

Figure 1 shows the experimental setup. The light source is an external cavity tunable laser diode (ECL-DL). The light from the ECL-DL is coupled into a dual-electrode Mach-Zehnder modulator (M–Z MZM) through a polarization controller. An externally triggered pattern generator with 2^5-1 pseudorandom bit sequences (PRBS) provides the baseband signal at a rate of

**CMR5 Fig. 2.** RF spectra of transmitted subcarrier signals (a) 3-GHz signal, (b) 5.5-GHz signal.

**CMR5 Fig. 3.** Recovered eye diagrams of 1-Gb/s channels after 500-m fiber (a) Baseband NRZ modulation (500 ps/div, 30 mV/div); (b) 3.0-GHz subcarrier channel (500 ps/div, 50 mV/div); (c) 5.5-GHz subcarrier channel (500 ps/div, 50 mV/div).
Fig. 1. Experimental setup.

Fig. 2. Eye diagrams with laser frequency at center of fiber grating when (a) only lower sideband is transmitted (b) only upper sideband is transmitted (c) both sidebands are transmitted.

Fig. 3. Eye diagrams with laser wavelength up-shifted by 10 GHz when (a) only lower sideband is transmitted (b) only upper sideband is transmitted (c) both sidebands are transmitted.


500 Mbps. The data is modulated by BPSK onto a subcarrier at a frequency $f_d = 12$ GHz. The signal is split into two and fed to two 90° hybrids through two different path lengths. The 90° outputs from each hybrid is summed with the 90° output of the other hybrid and the two resultant signals are used to drive the DL-MZM through bias 'T'. The DE-MZM is biased at quadrature. The two BPSK signals are thus carried on different sidebands of the optical carrier. The power before the RF power divider is 20dBm. An erbium-doped-fiber amplifier (EDFA) boosts the output optical power. At the receiver, both the upper and lower sidebands are separated by a reflective fiber grating (FWHM = 20 GHz) through an optical circulator (OC). The signal is detected by a lightwave converter (LPC 11982A). The output is connected to a low pass filter (LPF) followed by a digital oscilloscope (HP 54542C) to observe eye diagrams.

The experiment is performed at two wavelengths of the laser source. In the first case, the laser wavelength is chosen such that it lies at the center frequency of the fiber grating. This ensures that both sidebands are almost equally accepted. The experiment is then repeated with the laser wavelength up-shifted by 10 GHz. This ensures that the upper sideband is almost completely rejected, In each of the above cases the sidebands are first transmitted individually and then together through appropriate input to the DL-MZM.

In Fig. 2 the light source wavelength was at the center of the fiber grating. We can see from the eye diagrams that both sidebands are accepted nearly equally. The fact that the eye diagram deteriorates when we transmit both sidebands suggests that we are transmitting different signals in each of the sidebands.

In Fig. 3 the source wavelength is up-shifted by 10 GHz. As can be seen, the upper sideband is almost completely rejected resulting in an excellent eye diagram even when both the sidebands are transmitted.

The above results suggest that the "tandem" transmission was successful and that it is possible to transmit different information in both the sidebands.

In conclusion, we have successfully demonstrated the "tandem" single sideband technique and shown that it is possible to double the bandwidth efficiency of a link by transmitting different information in each of the two sidebands.