Phase-Modulated Subcarrier-Multiplexed Transmission Systems

Hoon Kim
National University of Singapore, Dept. of Electrical & Computer Engineering
4 Engineering Drive 3, Singapore 117576
Phone: +(65)6516-4936, Fax: +(65)6779-1103, Email: hoonkim@ieee.org

Abstract

We present phase-modulated subcarrier-multiplexed transmission systems. These systems not only offer better robustness against inter-channel fiber nonlinearities when used for multi-channel transmission but also enable us to utilize larger modulation index than amplitude-modulated counterpart.

Introduction

Transmission of radio-frequency (RF) signals over fiber using sub-carrier multiplexing (SCM) technology has a wide range of applications including common antenna TV (CATV), hybrid fiber-wireless, and analog true-time delay systems. Typically, those systems have exploited intensity modulation (IM) and direct detection (DD) scheme mainly thanks to its simplicity and cost-effectiveness.

In this paper, we present the phase-modulated (PM) SCM transmission system and its advantages over IM/DD counterpart.

PM SCM Transmission Systems

Fig. 1 shows the schematic diagram of the PM SCM systems. Each wavelength channel is modulated with SCM signals by using a phase modulator. After being combined with a wavelength-division-multiplexer, the signals are transmitted to the receiver over fiber. At the receiver, the phase information impressed on each channel is converted into the intensity information by a demodulator. For demodulator, we can utilize an optical filter which has a steep slope at the channel wavelength. A wavelength-offset wavelength grating router (WGR) or a delay interferometer followed by a WGR can also take the place of numerous demodulators. In either case, the filter functions as a frequency-to-intensity converter *not* as a phase-to-intensity converter and consequently we might need an analog electronic conversion circuit at the transmitter or receiver which integrates the SCM signals, because the integral of frequency with respect to time corresponds to phase. However, if the bandwidth of each SCM signal is much less than its respective subcarrier frequency (i.e., for slowly varying amplitude and phase modulation), the conversion circuit outputs the same amplitude and phase information as the input signal and thus is not necessary [1], [2].

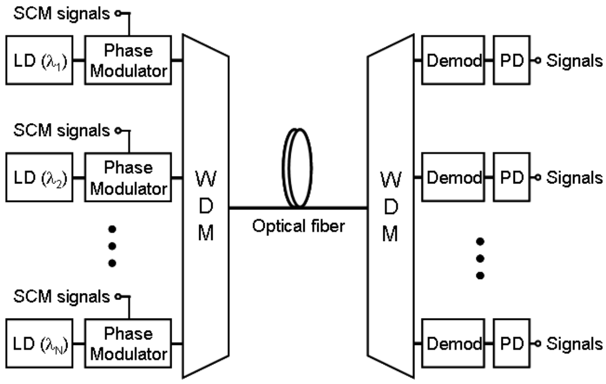

Fig. 1. Schematic diagram of a WDM PM SCM system

The major advantages of PM SCM systems over IM/DD SCM system can be summarized as follows:

1. High robustness against fiber nonlinearities.
2. Allows large modulation index for the re-modulation scheme.
3. High gain and low noise figure.
4. Simple transmitter.

The large tolerance of PM SCM systems to fiber nonlinearities comes from the fact that the optical intensity of PM SCM signal is constant at the output of the transmitter [2]-[4]. Even though the PM-to-IM conversion by fiber dispersion induces amplitude fluctuations, those fluctuations are much less than those of IM/DD systems, especially for the first several kilometers of the transmission fiber where the optical power is high and thus the effects of fiber nonlinearities are strong. We showed the robustness of PM SCM systems against inter-channel fiber nonlinearities through 2-channel experiment [2]. The RF-modulated pump channel co-propagated with a continuous-wave (CW) probe channel to measure the inter-channel nonlinear crosstalk. Fig. 2 shows the crosstalk versus the modulation frequency when the channel spacing is 10 nm. The fiber length was 25.4 km. For comparison, the crosstalk of the analog IM/DD system is also plotted together with the theoretical curves reported in [5]. The measurement and simulation data agree well with the theoretical curves. This figure clearly shows the high robustness of PM SCM systems against inter-channel fiber nonlinearities. One distinctive feature of the inter-channel nonlinear crosstalk of the PM system is that the

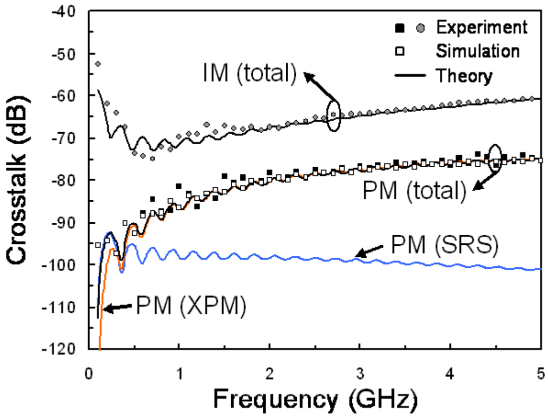

Fig. 2. Inter-channel crosstalk vs. modulation frequency. The channel spacing was 10 nm.

nonlinear crosstalk is very small near DC frequencies, which is quite high in IM systems and can be problematic for some applications such as analog CATV and hybrid wavelength-division-multiplexed (WDM) systems [5], [6]. Also shown in the figure is that cross-phase modulation (XPM) is the dominant source of inter-channel nonlinearities over nearly all the frequency range even at a large channel spacing of 10 nm. This is different from the IM/DD system where stimulated Raman scattering (SRS) crosstalk dominates over XPM at low frequencies but XPM becomes a major source of crosstalk as the modulation frequency increases. Fig. 2 shows that the PM SCM system suppresses inter-channel fiber nonlinearities by >15 dB, compared to the IM/DD system.

The constant optical intensity of PM SCM signals allows us to re-modulate the signals with an intensity modulator. This scheme can be used for wavelength-reuse scheme in radio-over-fiber (RoF) systems, as shown in Fig. 3. In order to make a remote base station (RBS) cost-effective and reliable, the optical source (i.e., laser diode) is located only at the central base station (CBS) and the RBS reuses the optical downstream light to modulate the upstream signals [7]-[10]. However, if both the downlink and uplink transmission utilize the IM/DD scheme, the modulation index of the downlink signal should be sacrificed to allow for the minimum required performance of the uplink signal. In addition, an optical amplifier might be required at the RBS to offset the power loss caused by signal tapping or filtering of optical carrier [11], [12]. These would weaken the original purpose of developing a centralized light source to remove the light source from the RBS and making the RBS simple and compact. These problems can be resolved by using phase modulation for downlink and intensity modulation for uplink [7]. For example, thanks to the constant intensity of the PM downlink, the constraint on modulation index of the downlink signal can be considerably relaxed compared to the SCM systems based on IM downlink/uplink signal. This brings the better power budget of the uplink signal even without

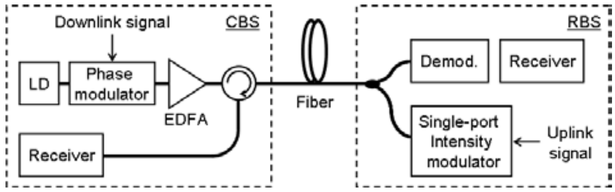

Fig. 3. PM radio-over-fiber systems based on loop-back re-modulation.

an optical amplifier in the RBS by making it possible to optimize the coupling ratio of the optical coupler in the RBS to the advantage of the uplink signal.

High RF link gain is another advantage of the PM SCM system over conventional IM/DD SCM systems [13], [14]. However, this advantage comes at the expense of the bandwidth limitation. Fortunately, the required bandwidth of SCM system is typically limited to certain frequency bands. With a judicious choice of the demodulator, thus, we can enjoy the high RF link gain of the PM SCM system.

The PM SCM system utilizes a phase modulator, which is simpler than a Mach-Zehnder modulator in structure and does not require a bias control circuit. Thus, the transmitter of PM system is more robust and reliable than that of IM system. It is particularly advantageous in some applications where the transmitter is placed in a harsh environment such as on the wingtip of aircrafts [13].

Conclusions

PM SCM systems offer some benefits over IM/DD counterpart, including the robustness against fiber nonlinearities, no compromise between uplink and downlink performance, high RF link gain, and simple transmitter. Although these advantages comes at the expense of limited bandwidth and complex receiver, the PM SCM systems would be beneficial to some applications such as WDM RoF access networks and sensor systems.

References

1. H. Kim, *IEEE Photon. Technol. Lett.* (2008) p. 243.
2. H. Kim *et al.*, *Optics Express* (2008) p.20687.
3. F. Bucholtz *et al.*, Microwave Photonics Conference (2004) paper MC-9.
4. M. Rogge *et al.*, Conference on Lasers & Electro-Optics (2005) paper CMH2.
5. M. Phillips *et al.*, *J. Lightwave Technol.* (1999) p. 1782.
6. H. Kim *et al.*, *IEEE Photon. Technol. Lett.* (2001) p. 1118.
7. W. Hung *et al.*, *IEEE Photon. Technol. Lett.* (2003) p. 1476.
8. J. Prat *et al.*, *IEEE Photon. Technol. Lett.* (2005) p. 702.
9. X. Yu *et al.*, *IEEE Photon. Technol. Lett.* (2008) p. 2180.
10. H.-C. Ji *et al.*, *IEEE Photon. Technol. Lett.* (2009) p. 9.
11. Z. Jia *et al.*, *IEEE Photon. Technol. Lett.* (2006) p. 1726.
12. L. Chen *et al.*, *IEEE Photon. Technol. Lett.* (2006) p. 2056.
13. V. Urick *et al.*, Avionics, Fiber-Optics and Photonics Technology Conference (2007) paper TuB1.
14. V. Urick *et al.*, *IEEE Tran. Microw. Theory Tech.* (2007) p. 1978.