Optical sampled subcarrier multiplexing scheme for nonlinear distortion reduction in lightwave CATV networks

Wai Hung, Man-Hong Cheung, Siu-Ting Ho, Lian-Kuan Chen and Chun-Kit Chan

A nonlinear distortion reduction scheme is proposed and demonstrated for subcarrier multiplexed optical CATV networks based on optical sampling and optical time division multiplexing techniques. Intermodulation distortion is reduced by about 10 dB for a 40-channel system.

Introduction: One of the major impairments in subcarrier multiplexed (SCM) optical CATV systems is the presence of intermodulation distortion (IMD) [1] caused by the nonlinearity of various optical or electrical components in the whole system. Several IMD reduction approaches have been previously proposed, which include improving the linearity of the optical components; using pre-distortion/feed-forward compensation techniques; and performing careful RF frequency planning. In this Letter, we propose and demonstrate a new distortion reduction technique based on optical time division multiplexing (OTDM) and optical sampling. By splitting the composite sub-carriers into several orthogonal OTDM channels, IMD can be reduced substantially. The proposed multiplexing/demultiplexing process is shown to induce negligible additional distortion. Also, the scheme does not require an additional wavelength or fibre link. No frequency conversion is necessary.

Principle: Among all the nonlinear distortions, third-order IMD is the most difficult to tackle as it lies within the SCM channel frequency band. It has been shown that the number of third-order IMD components is proportional to N^2 for an N-channel SCM system [2]. Thus an intuitive method to reduce the effects of IMD is to divide the subcarrier channels into several groups, each is carried by a separate wavelength or fibre link. This method inevitably requires extra system resources, which could otherwise be used to deliver other services, such as high-speed data services.

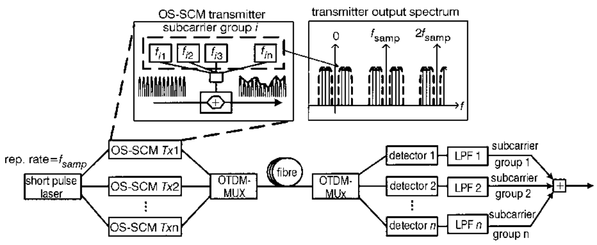

Fig. 1 *Nonlinear distortion reduction scheme using OS-SCM and OTDM*

Subcarriers are divided into M groups, each group may contain up to N subcarriers, $M > N$, $i \leq M$, $n < N$

In view of this, we propose a technique, called optical sampled subcarrier multiplexing (OS-SCM), to perform IMD distortion without using additional wavelength or fibre resources. Fig. 1 shows the schematic diagram for an OS-SCM based distortion reduction system. Subcarrier channels to be transmitted are divided into several subcarrier groups. Assignment of frequencies in each group can follow a fixed frequency spacing approach. Alternatively, optimisation algorithms previously implemented in [3–5] can also be employed to divide the frequencies. An optical short pulse laser is used as the light source for a multiple number of OS-SCM transmitters. At each OS-SCM transmitter, the composite RF signal in each respective subcarrier group modulates the optical intensity of its optical pulse train through an optical sampling technique. For a group of subcarriers having a maximum frequency f_{max}, the repetition rate of the optical pulse train, f_{samp}, must be greater than $2f_{max}$ in order to meet the Nyquist criterion. Theoretically, such a sampling modulation scheme does not degrade the carrier-to-noise ratio (CNR) of the subcarrier signals [5]. Furthermore, as shown in our experimental results, it does not introduce additional intermodulation distortions. An optical time-division multiplexer is then used to 'bit-interleave' the modulated pulse trains from all OS-SCM transmitters to form an OTDM signal. At the receiving end, a corresponding optical time-division demultiplexer is used to separate the individual pulse trains for each subcarrier group, each of which is then detected by an optical detector. The detected signals are lowpass filtered to recover the original composite RF signals for all subcarrier groups.

Ideally, the number of RF frequencies contributing to IMD in each time-domain channel is reduced by this method and hence the intensity of IMD can also be reduced. In actual implementation, care must be taken to select an appropriate pulse source and OTDM demultiplexer. Pulses sources having low extinction ratio are undesirable as multiplexing of such a pulse train would result in optical beat interference (OBI) among OTDM channels during the interleaving process. The optical pulses also need to be sufficiently short to avoid inter-channel interference. Similarly, the OTDM demultiplexer at the receiving end should also have a high extinction ratio and sufficiently narrow switching window in order to provide a high degree of isolation between adjacent time channels.

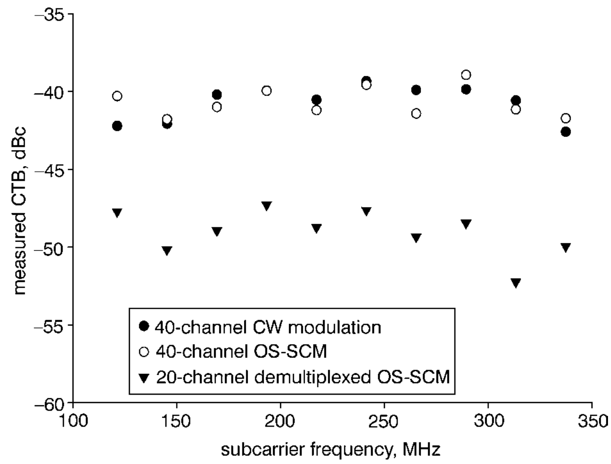

Fig. 2 *CTB measurement*

Experimental investigation: To investigate the feasibility and measure the performance of the proposed distortion reduction scheme, we applied it experimentally to a 40-channel SCM system.

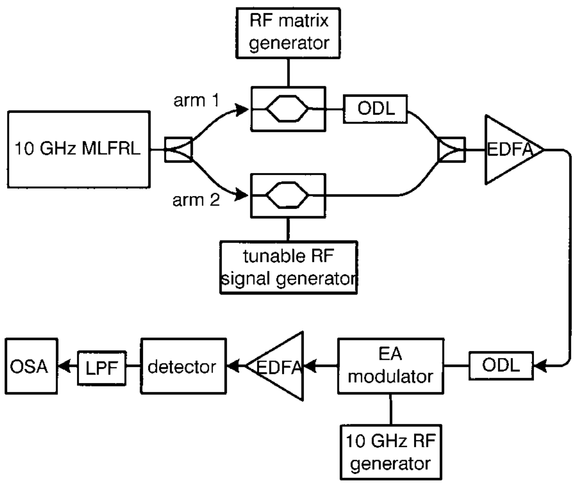

Fig. 3 *Experimental setup*

To obtain a set of baseline values for comparison, we first measured the composite triple beat (CTB) values that resulted from a conventional 40-channel SCM system using a CW laser as the light source. In addition, the resultant CTB values for an identical 40-channel system using optical sampling with a modelocked fibre ring laser (MLFRL) as the 10 GHz optical pulse source was also measured. These two sets of baseline values, (as shown in Fig. 2), indicate that negligible intermodulation distortion was introduced by replacing the CW source with an optical sampling pulse source. Fig. 3 shows the experimental setup used to investigate the performance of the optical sampled subcarrier multiplexing scheme for nonlinear distortion reduction. The optical pulse train generated by MLFRL was split into two arms, each passed through an optical modulator. The one passing through arm 1 was modulated by a matrix generator while the other passing through arm 2 was optionally modulated by a tunable RF generator. The two pulse trains were then time-multiplexed using optical delay lines (ODL) to form a 20 GHz OTDM signal. At the receiving end, a 10 GHz electro-absorption (EA) modulator was used to demultiplex one of the time channels for RF spectrum measurement. The EA modulator was chosen for OTDM demultiplexing due to its high extinction ratio (~22 dB). The switching window of the EA modulator was 50 ps which was narrow enough to demultiplex 20 GHz pulses but much larger than the width of modelocked pulses (~3 ps). As a result, the distortion induced by the non-uniform demultiplexing window of the EA modulator could be ignored.

To determine the linearity of the mux–demux process, we first used two subcarrier tones (295.25 and 301.25 MHz) to modulate the two fibre arms individually. One of the fibre arms (the one modulated with 301.25 MHz carrier) was then demultiplexed by the EA modulator. As observed from the output spectrum shown in Fig. 4, the unwanted RF frequency (295.25 MHz) was suppressed substantially by 58.9 dB. This showed good isolation between adjacent time channels. In addition, the RF spectrum of the demultiplexed waveform showed no two-tone-third-order distortions. This indicated the mux–demux process introduces no nonlinear distortions. The RF spectrum in Fig. 4 also shows some additional periodic frequency terms as indicated by the dashed circle. These frequency terms were residual cavity modes generated by the long fibre cavity of MLFRL. Such frequency spikes can cause signal quality degradations. However, it was not an intrinsic degradation due to OS-SCM and they could be completely eliminated by replacing the MLFRL with other short pulse sources, such as short-cavity mode-locked laser diodes or gain-switching lasers which also have the desirable property of being relatively low cost.

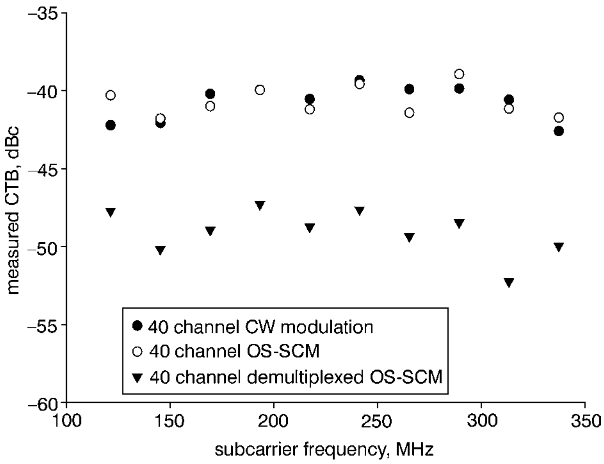

Fig. 4 *Two-tone linearity test for mux–demux process*

Inset: Spectrum of two RF components before demultiplexing, 10 dB/div, 2 MHz/div, central frequency = 297.87 MHz

To measure the extent of distortion reduction, we uniformly chose 20 subcarrier channels out of the original 40 channels. The composite signal was generated by the matrix generator and it was used to modulate arm 1. Arm 2 was left unmodulated from the previous measurement optical isolation between the two time-division groups was adequate to suppress additional distortion generated from carriers beating between two OTDM channels. The modulated pulse train from arm 1 was then demultiplexed at the receiving end and the CTB value was measured shown in Fig. 4. It is shown that in most of the channels, CTB was reduced by 10 dB when compared with the baseline cases. These confirmed the effectiveness of our nonlinear distortion reduction scheme.

Conclusions: We have proposed and successfully demonstrated a new nonlinear distortion reduction scheme for a subcarrier multiplexing system with the use of optical sampling and OTDM mux–demux. Subcarrier frequencies originally intended to be transmitted on a single wavelength channel are separately modulated onto different time channels. The time domain isolation has reduced the number of RF frequencies contributing to IMD. Experimental results showed that the use of OS-SCM induced negligible nonlinear distortion and the OTDM mux–demux process was able to provide sufficient isolation without introducing any additional nonlinear distortions. A CTB reduction of 10 dB was observed for a 40-channel SCM system.

Acknowledgment: This work was partially supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region (Project CUHK 4372/99E).

11 June 2002

Electronics Letters Online No: 20021187

DOI: 10.1049/el:20021187

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