should be small (i.e. three or four). For example, the necessary bandwidth of four-cluster rings can be reduced to 62.5%.

The second issue concerns the flexibility in terms of the capacity allocated to the clusters under changing load conditions. When fixed BSFs are introduced into the cluster, the capacity of the cluster is bounded. The hybrid ring cannot support changes in the load conditions that are often seen in practical networks. To cope with this situation, we have developed a new technique: the basic concept involves creating a shared band available to all clusters in addition to the bands dedicated to the clusters. When traffic demand in a cluster exceeds its dedicated capacity, the shared band is apportioned to the cluster. We analysed the effect of a shared band on flexibility by using a variable load model, where the total number of channels provided in the ring was 100, and each channel was destined for every end node with identical probability. This corresponds to the multinominal distribution model. The blocking probability (P_B) under 100% load (the worst case) was calculated for two cases: with and without a shared band. The effect of clustering and a shared band under a variable load is shown in Fig. 3. P_B decreases as the number of clusters increases under a given number of wavelengths, because a wider wavelength-band can be assigned to the cluster due to wavelength reuse. It steeply decreases with the shared band. 10 to 20 shared channels were needed to achieve 10^{-2} blocking probability in this case. There is some saturation, and the number of clusters should be small (i.e. three or four again). For a four-cluster ring with a ring capacity of 100 channels and $P_B = 10^{-2}$, the necessary number of wavelengths can be reduced to 138, while 198 wavelengths are needed in the pure B&S ring. Thus, the necessary bandwidth can be reduced to ~60% even in the variable load model.

In summary, we have introduced a hybrid design for DWDM ring networks. It is shown that the filter guard-band cancellation technique and the partial bandwidth-sharing technique are useful for improving the wavelength efficiency and enhancing flexibility, while keeping the node complexity to a minimum.

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Robustness of DPSK direct detection transmission format in standard fibre WDM systems

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The practicability of using phase modulation in a 16 channel 10Gbit/s system over 1600km of standard SMF with simple dispersion compensation and the robustness in presence of ASK modulated channels has been shown for the first time.

Introduction: Phase shift keying (PSK) and differential phase shift keying (DPSK) of optical carriers principally provide superior receiver sensitivities compared to amplitude shift keying (ASK) modulation formats [1]. However, even the more simple DPSK scheme is not used in practical systems for three reasons: the use of optical amplifiers has eliminated the need for high receiver sensitivities, an additional phase demodulator is necessary and in principle the wavelength stability and carrier phase noise requirements are high. However, for high bit rate systems these restrictions become more relaxed and since phase-modulated signals exhibit constant power flow, the nonlinear effects are diminished. Furthermore, a bipolar reception is possible and advantageous for varying power levels to be expected in future burst-mode optical networks for IP traffic [2]. A long haul WDM transmission of 4 × 10Gbit/s DPSK signals over dispersion shifted fibre (DSF) has already been demonstrated in [3]. In this Letter we address the transmission performance of a 16 channel DPSK system, and the robustness of one DPSK channel in the presence of adjoining ASK channels on standard single mode fibre (SMF ITU-T G.652) links.

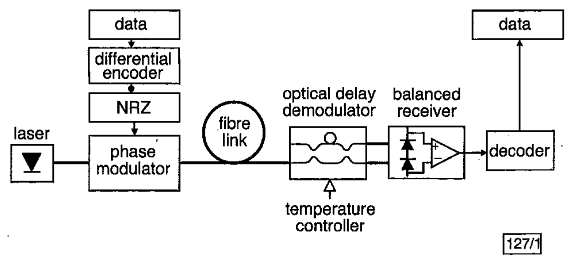

Fig. 1 *Schematic diagram of DPSK-DD transmission*

Table 1: Required accuracy in transmitter-demodulator centre frequency alignment

Bit rate [Gbit/s]	2.5	10	40
Δf [GHz]	0.25	1	4

DPSK transmission features: Fig. 1 shows a schematic diagram of a transmission link with the DPSK modulating equipment at the transmitter site and at the receiver site a DPSK demodulator followed by a direct detection (DD) balanced receiver. The optical delay line demodulator in a Mach-Zehnder (MZ) configuration transforms the DPSK signal into a bipolar ASK signal and performs differential decoding.

The possible benefits of DPSK systems for future networks are summarised as follows:
enhanced receiver sensitivity
constant channel power for reduced nonlinear effects on fibres
compatibility with standard ASK equipment
bipolar reception for burst-mode operation in future optical networks
permanent channel monitoring for management purposes through definite idle channel states (CW carriers)

However, some drawbacks are encountered with DPSK formats:
an additional Mach-Zehnder demodulator is necessary for direct detection
potential degradation through PSK-ASK conversion of dispersive fibres
greater optical frequency stability requirements

The delay of the MZ in Fig. 1 must have a duration of approximately one bit but fine tuning Δf of the multiple frequency response peaks relative to the transmitter centre frequency must be within a fraction of the bit rate. Fine tuning can be performed by temperature control (see Fig. 1).

By simulation and experiment the corresponding values given in Table 1 have been proven to be sufficient. Surprisingly, high bit rates favour the DPSK scheme due to relaxed tolerances.

Chromatic dispersion compensation: A limiting effect for high distances is PSK-ASK conversion by fibre dispersion. Subsequent nonlinearities irreversibly degrade the PSK or DPSK signal. By numerical simulation, several dispersion compensation methods were evaluated. A 100% periodical post-compensation arrangement (see Fig. 3) showed best results. This scheme best avoids the coincidence of high accumulated dispersion and high power level. Fig. 2 depicts a contour plot of the system penalty of a DPSK 10Gbit/s single channel after 20 compensated sections (1600km of SMF), as a function of input powers into SMF and DCF, respectively. A minimum penalty of < 3dB is expected. $P_{SMF} = -1$dBm and $P_{DCF} = -2$dBm were selected for the experiments.

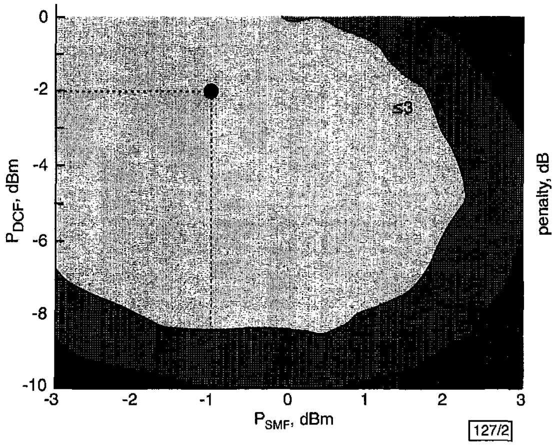

Fig. 2 *Power level tolerances for 10Gbit/s DPSK channel over 1600km SMF*

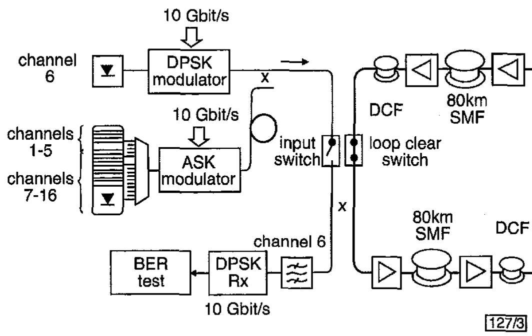

Fig. 3 *WDM loop testbed setup with two identical SMF-DCF optical transmission sections*

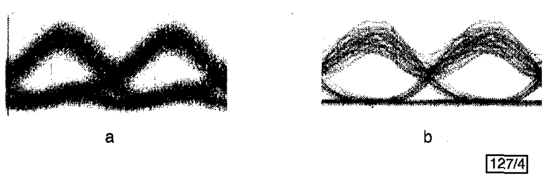

Fig. 4 *10Gbit/s NRZ-DPSK eye diagrams*

a Experimental
b Simulated

Experiments: The WDM loop testbed [4] was configured for testing pure DPSK transmission and DPSK within the ASK environment, respectively. Fig. 3 shows the configuration of the DPSK modulated channel 6 and 15 channels with ASK modulation. For comparison, single channel and WDM measurements were all performed on channel 6. For a given transmission length, a low increase in the receiver sensitivity penalty is a measure for the robustness of the DPSK channel in the ASK WDM environment. The 16 channel wavelengths ranged from 1543.73 to 1555.74nm with 100GHz spacing according to ITU-T G.692. The BER is evaluated for channel 6 at 1547.72nm. Instead of the balanced receiver in Fig. 1*a* single-pin receiver was used in the experiment. The back-to-back sensitivity was −37dBm at BER = 10^{-9}, similar to the ASK back-to-back sensitivity in previous experiments [4]. This indicates proper operation of the modulation-demodulation system. Characteristic eye diagrams of the demodulated DPSK signal are shown in Fig. 4.

Figs. 5*a* and *b* depict the penalty-distance diagram extracted from simulated and measured BER data, respectively. The simulated and measured results agree very well. For a transmission length of 1280km (8 loops), the penalty is only 2dB for a single DPSK channel. It is increased by only 1dB for 16 DPSK channels and by 5dB for the 15 neighbouring ASK channels, which can be attributed mainly to the cross-phase modulation from the nearest ASK channels.

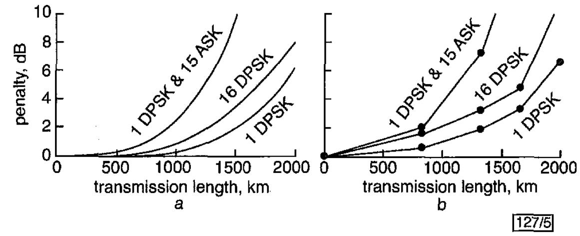

Fig. 5 *Penalties for DPSK channel 6 in different configurations*

a Simulated
b Measured

Conclusion: The advantages of optical phase modulation in view of high bit rate and high power channels as well as for packet switched networks have been shown. For the development of future city networks, for example, coexistence with present standard systems is important. We have shown the successful application of the DPSK transmission format to standard fibre WDM systems and the use of DPSK and ASK formats on the same fibre infrastructure for the first time.

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160Gbit/s all-optical demultiplexer using hybrid gain-transparent SOA Mach-Zehnder interferometer

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The authors report on a 160Gbit/s all-optical demultiplexer based on gain-transparent cross-phase modulation in semiconductor-optical amplifiers. The switch comprises a hybridly set up Mach-Zehnder interferometer with switching windows as short as 2.5ps and an input power dynamic range of 50dB.