Klaus Panzer

Bidirectional optical transmission with BIDI:
Just one fiber to the subscriber

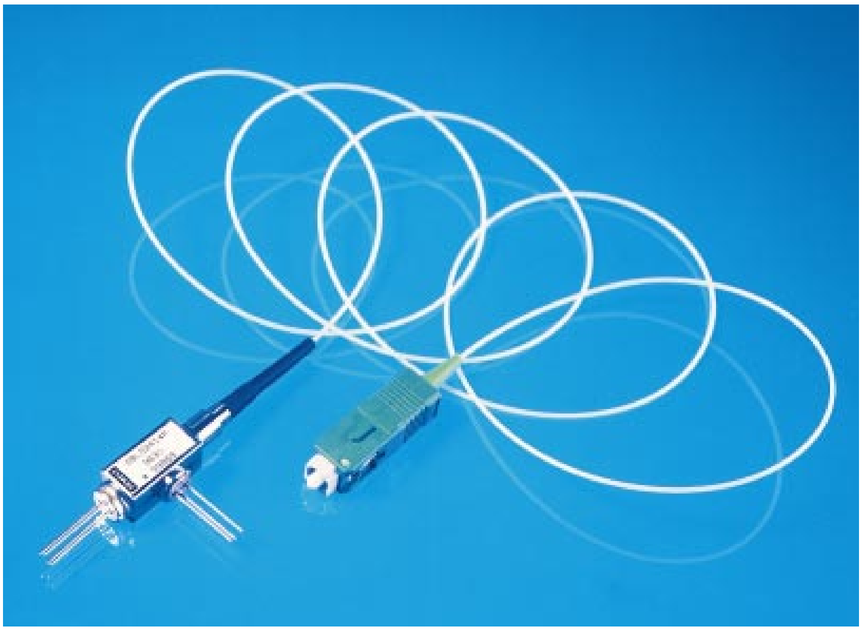
With the Siemens BIDI module, bidirectional optical transmission systems can be installed at reasonable cost right up to the subscriber's network termination. A variant of the BIDI module is being developed to make bidirectional transmission with a single fiber more economical than a two-fiber solution, regardless of route length.

Bidirectional optical transmission via a single fiber calls for special measures to couple the light in and out. Various procedures are available to separate the directions of transmission at the ends of the route. These procedures differ, depending on whether a single wavelength or two different wavelengths are used. Separation can done with fiber couplers or in free-beam optics. Beam separation in the BIDI® module is based on tried and tested free-beam optics. In the future, integrated optical components will also be available for this function.

Building BIDI modules from standard components

The basic building blocks of the BIDI module (Fig. 1) are a laser diode and a photodiode, each housed in a TO package. The widely diverging laser beam is already focused by an optical system in the laser subassembly. In the same way, the light from the optical fiber is focused onto the small photosensitive surface of the photodiode. A mirror designed as either semitransparent or wavelength-selective (dielectric filter) lets the transmit signal pass through while the receive signal is reflected and coupled out. The mirror is introduced into the beam so that the transmitter and receiver can be arranged at right angles to one another, allowing maximum leeway for circuit layout at both the transmit and receive ends.

Fig. 1 The BIDI module combines a laser diode and a photodiode in standard TO packages



A key advantage of this module is that the transmitter and receiver make use of standard components in TO packages that are manufactured and tested in volume. A solid metal casing is used to house the subassemblies and fiber mount. It is provided with holes for the optical beam and for insertion of the TO components and fiber coupling unit .

Rugged construction with WDM

Bidirectional optical transmission can be implemented either with one wavelength (separation with 3 dB beam splitters), or with two using wavelength division multiplexing (WDM). The largely loss-free beam separation of WDM, its large tolerances for the wavelengths and its ability to use stop filters add up to a very rugged design for WDM systems operating at 1300/1550 nm. This accounts for the high market acceptance of these modules. However, critics occasionally point to an apparent flaw in the WDM 1300/1550 nm design: it uses from the outset both of the optical fiber's wave-

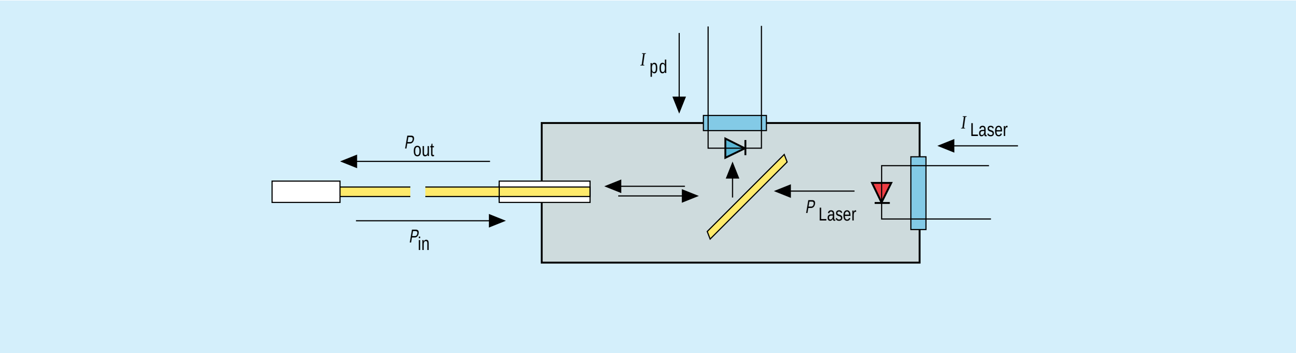


Fig. 2 Definition of crosstalk parameters in the module

length windows which are ideal in terms of attenuation.

For this reason, DFB lasers are currently being developed for WDM in one window, e.g. 1300 nm ± Δλ. Optical filters with the required precision are already available.

Only one window is likewise assigned for separation of directions using beam splitters. With these BIDI modules, however, particular attention must be paid to crosstalk. As a rule, they cannot be used for full-duplex mode, i.e. simultaneous transmission in both directions [1].

Eliminating crosstalk

Parameters such as transmit power, receive sensitivity and optical crosstalk must all be considered in the design of a transmission system based on BIDI modules. The reference point is the module's optical input into or output from the access fiber.

The lasers built into the TO transmitters can be used at up to 85 °Cand deliver up to 8 mW of optical power at the laser mirror. The laser can be modulated up to several gigahertz. The bandwidth is limited less by the chip than by the external circuitry. As well as lasers with an emission wavelength of about 1300 nm, a version with a wavelength of 1550 nm is available for WDM. It allows up to 2 mW to be coupled into the fiber.

One of the most important parameters in specifying bidirectional transmission is the crosstalk between transmission paths (Fig. 2). The optical receive power P_{in} in the module is in the order of 100 nW, compared with a transmit power P_{out} of several milliwatts – about one thousand times greater. Optical crosstalk cannot be avoided with this large ratio.

Crosstalk may be produced in two ways. First, scattered light or reflections within the module can lead to light from the transmitter (P_{laser}) reaching the receiver directly and generating an interfering photocurrent I_{pd} (near-end crosstalk). Second, light can be reflected at joints or splices along the transmission route and then coupled into the receiver (far-end crosstalk). The WDM module is designed for crosstalk attenuation of 50 dB by means of additional optical stop filters at the receivers. At a receive power of –35 dBm and transmit power of –3 dBm, up to 10% of the transmit power can be reflected in the cable system without reducing the sensitivity. Interference caused by optical crosstalk is thus almost completely ruled out with the sensitivities attainable for high data rates.

Crosstalk attenuation of about 30 dB can be achieved by using the BIDI with beam splitters and a reflection-free termination. To take advantage of this, however, reflections along the optical route must be minimized.

BIDI modules in the subscriber domain

Optical communication at rates of several gigabits per second has been introduced on a large scale in long-haul transmission systems. But feeders are important to subscribers. Extensive networks of conventional copper cables are still in widespread use. Thanks to sophisticated coding and correction procedures, amazingly high data rates can still be obtained in these conventional networks. But as more and more unshielded adjacent cables are utilized to full capacity, the limit is in sight. As part of the OPAL project [2], large areas of the subscriber domain in eastern Germany, where the copper network was in need of modernization, have been equipped with optical fibers. The BIDI module is being used for many of 1.2 million subscriber lines installed by Germany's Telekom in this project.

Economic considerations play a key part in the introduction of optical fibers in the subscriber access network. Major efforts have therefore been mounted to offer customers the right technological solutions at reasonable prices, and the introduction of bidirectional transmission via a single fiber is particularly significant in this context.

There are two approaches to optimizing costs in the bit transport system:
- the passive optical network (PON), and
- bidirectional optical transmission.

In the first approach, a passive optical network with a tree structure (instead of a star network with point-to-point connections to each subscriber) is selected to reduce costs in the switching equipment and cable network. The PON offers considerable savings in fibers and electro-optical converters at the central office because a single transceiver can serve many subscribers. This advantage is partly offset, however, by the higher costs of the beam splitter and the increased electric power required for bidirectional operation in a tree network.

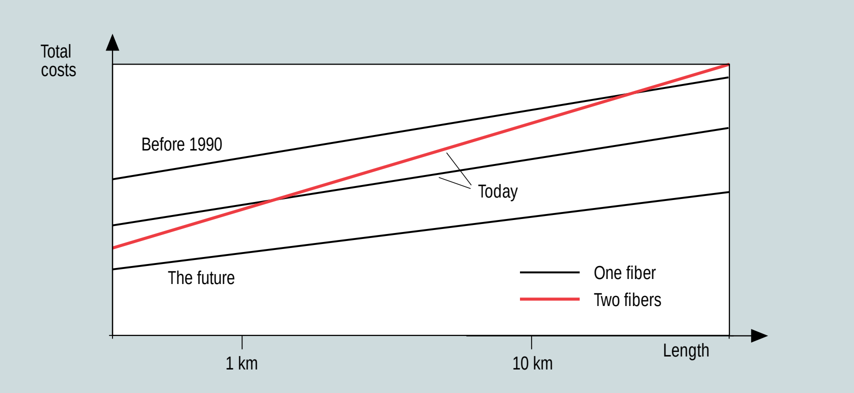


Fig. 3 With a recently developed variant of the BIDI module, single-fiber transmission systems are becoming more and more viable than two-fiber solutions

Separation problems can also cause problems because a large power budget (ratio of transmit to receive power) is to be implemented. Separation factors greater than 32 are scarcely feasible. Recently, however, there has been a tendency to replace passive separation by active separation. Experience gained in operating the networks has shown that a pure PON reaches the limits of its transmission capacity relatively quickly, while networks with active splitters are more flexible. The final links to the subscriber must be particularly low-cost to ensure that optical systems are also economical in comparison with copper.

Only two packages and two connectors are required for bidirectional transmission along one fiber, compared with four packages and four connectors for a transmission route with two fibers. This represents significant savings in material and installation costs, but must be offset against more expensive beam-splitting techniques.

Cost-benefit analyses have frequently been carried out to determine the minimum route length from which transmission along a single fiber is more economical. Since many factors must be considered in these calculations, a statement can only be made about the order of magnitude. Whereas the payback distance was about 10 km when the first BIDI module was used, this figure has now dropped to below 1 km (Fig. 3). Ongoing development of BIDI aims to house the entire transceiver in a TO package. With such a component, bidirectional transmission will always be more economical than the two-fiber solution, regardless of distance.

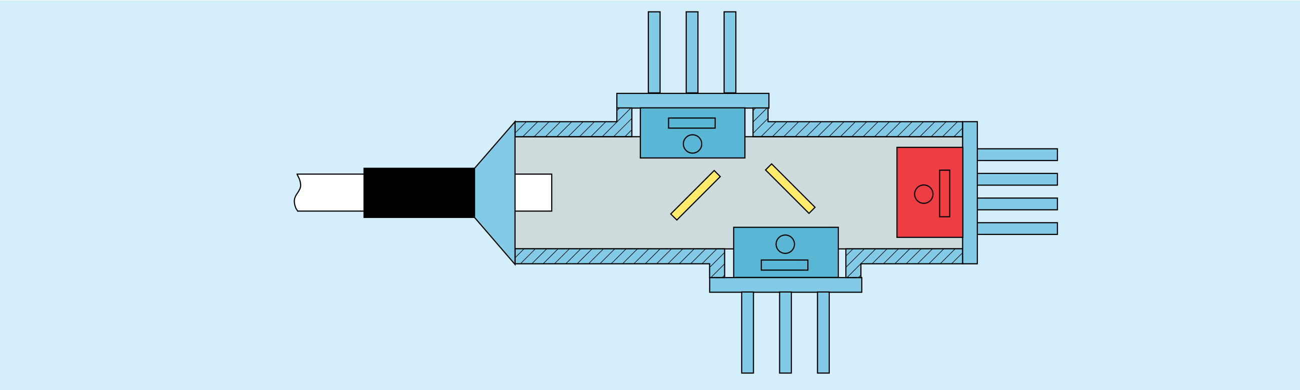
Three groups of module variants

If a wavelength of 1550 nm can be used, the WDM-BIDI design for 1300/1550 nm is ideal for a PON with a high splitting factor. For systems operating in half-duplex mode (ping-pong or time-compressed multiplex, TCM), modules with simple beam splitters and transmitters using one wavelength (1300 nm) are suitable. They also permit a relatively high power budget. For new systems with active splitters, a module is being developed for short subscriber links

	Power budget	Transmission mode
WDM module in standard package	Very large	Full-duplex
Module for one wavelength with 3 dB beam splitter in standard package	Large	Half-duplex
Low-cost module in compact package (under development)	Small	Full-duplex

Table 1 Three groups of module variants

Fig. 4 A three-port BIDI module with an additional receiver diode is suitable for TV distribution



(Table 1); its costs have been matched to the small power budget.

Network extension with a third wavelength

If the transmission capacity of a network can be extended by means of an additional optical signal using a vacant wavelength, this extension can be implemented in the module (Fig. 4). As part of a European research project [3], modules of this kind have been tested for transmission of the interactive and distribution services on one fiber in a pilot project. The interactive services were transmitted on an optical wavelength (1300 nm) and separated by beam splitters. The signal for cable television (1550 nm) was fed into the network at a suitable point and received at the subscriber end by an additional photodiode in the module.

Miniaturization continues unabated

Implementation of modules in integrated optics is seen as a further milestone in the development of the BIDI system. Prototype modules which use waveguide structures to separate the directions of transmission have already been developed in research programs, but are not yet advanced enough for volume production. In hybrid design technology, on the other hand, there is scope for further miniaturization. Work is currently in progress to accommodate the entire bidirectional transceiver function in a single TO package instead of in a module with two TO components (Fig. 5). First samples have been produced and successfully tested in the laboratory.

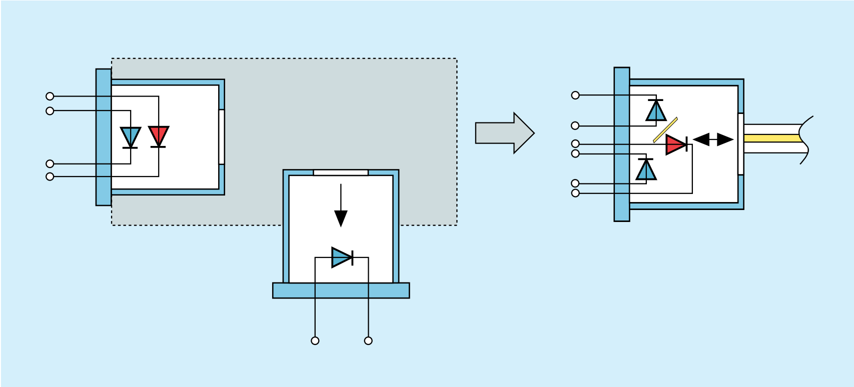


Fig. 5 Progressive miniaturization will accommodate all the functions of the transceiver for bidirectional transmission in just one TO package

The BIDI module thus offers a mature product for the forthcoming large-scale installation of optical fiber in subscriber access networks. Where alternative solutions are required, its modular design allows fast and flexible response to market requirements. □

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Klaus Panzer, Dr.-Ing.,

began his career at Siemens in the Central Telecommunications Laboratory in Munich. Since 1976, he has been involved in designing optical transmission systems for video signals and various pilot projects. Dr. Panzer (51) is now responsible for optoelectronic components applications engineering in the Semiconductor Group.