Active and Passive Fibre Components

W. J. Stewart

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Active and passive fibre components

By W. J. Stewart

Plessey Research & Technology (*Caswell*) *Ltd, Allen Clark Research Laboratories, Caswell, Towcester, Northamptonshire NN*12 8*EQ, U.K.*

The development of optical fibres for transmission has given us an advanced technology capable of producing waveguides of unequalled transparency and axial uniformity. This can be adapted to produce a range of active and passive components that have many advantages, including their suitability for connection into optical fibre systems. These may in turn enable more complex frequency-selective systems to be built economically.

Passive components include resonators and reflectors with very low loss and linewidths that are comparable with the modulation rates, possibly allowing radio type filtering and separation; splitters and separators with a wide variety of characteristics and polarization-selective components. In each case the performance achieved is better than that achieved by any other method.

Active devices include laser sources and amplifiers of various types and nonlinear switches and pulse compressors; these too show performance ahead of that achieved by other means.

This paper reviews these results and discusses applications to broadband networks.

Introduction

The modern telecommunications fibre is cheap, extremely transparent, uniform over metres to near-atomic levels and is able to withstand high optical powers. The information bandwidth available from a single fibre is now sufficient to provide several voice channels for everyone on Earth, and an integrated service digital network (ISDN) channel for everyone in Europe. Nor does this require any more power than is available from a conventional injection laser (with ideal detection, real detectors require one hundred times more). Recognition of this has led to growing interest in networks that spread the signal from a single laser across many receivers like a confined radio system, and which therefore require passive components to split the signal. The performance available from off-the-shelf components today is shown by the shaded area in figure 1, where the points represent real or projected systems.

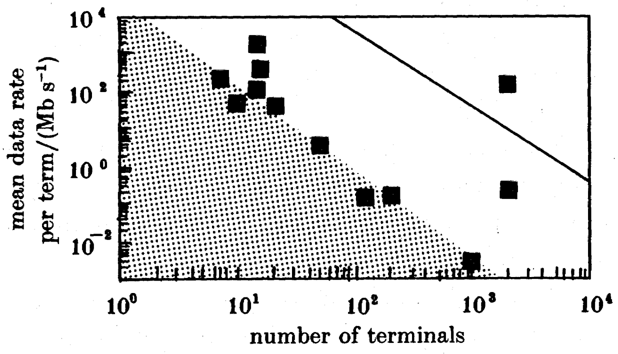

Figure 1.

The fibre–fibre fused coupler is the most successful component for achieving this, and larger splitters can be assembled from individual examples. At present no other approach can compete on price or performance, and the fibre device can also offer fine wavelength selectivity.

FIBRE SENSITIZATION

The standard fibre types are very insensitive to internal or external disturbances of any kind, as a deliberate feature of their design. To make a device this effect must in some way be evaded, the principal means used being the following.

(i) Tapering to reduce the external diameter, causing the field to penetrate to the outer surface of the cladding; this is the method used in couplers.

(ii) Polishing away some of the cladding to expose the core; this is used in the grating reflectors described below.

(iii) Increasing the power in the fibre until nonlinear effects are significant, for example, in Kerr devices or Raman amplifiers.

(iv) Making special fibres that incorporate structures close to the core, for example Hi–Bi fibres, electro-optic fibres and polarizers.

(v) Incorporating a dopant into the core to make optically pumped active devices such as amplifiers of fibre lasers.

The remainder of this paper is devoted to examining the kind of devices that can be produced in this way, starting with the more conventional devices and looking towards the more complex.

OPTICAL FILTERS

The conventional fibre–fibre coupler can be made into a wavelength-selective device, generally with fairly coarse selectivity based upon differential delay between symmetric and antisymmetric modes in the coupler region. A typical selectivity would be about 30000 GHz.

Grating structures imposed on the fibre externally or during manufacture can cause selective interaction between co-propagating modes of different polarization in a high-birefringence fibre. The linewidth obtained depends upon the length of fibre used and the birefringence; typical values would be *ca.* 200 GHz m^{-1}, with lengths of a few metres being practical.

A backward wave grating coupler, that is a fibre reflector, can be made by holographic techniques on an exposed core structure, and has given selectivities of *ca.* 100 GHz mm^{-1}, with lengths of a few millimetres being practical. Resonant versions of this structure can be 10 or perhaps even 100 times better than this.

Resonators made by using a loop of fibre and a coupler have linewidths ultimately limited only by the decay time of a light signal in the fibre, about 0.1 ms. This implies kilohertz linewidths, and these have been achieved.

Various permutations of the above are possible, and the use of gain can offset losses in resonators with a corresponding reduction in linewidth, so that the use of a fibre reflector, for example, with a fibre laser has given megahertz linewidths and with an injection laser 3 kHz. The difference reflects the different laser characteristics.

These linewidths are narrow enough, and the components potentially cheap enough, to allow frequency-selective channel selection (wavelength-division multiplexing (WDM)) with anything from a few to several thousand channels.

Doped fibres

Doping the core of a fibre with a small amount of an active ion, for example neodymium or erbium, can result in the fibre being optically pumpable to make an amplifier or laser. In principle this is just like a conventional glass laser, but the fibre configuration has many advantages, including efficient guided-wave pumping, very favourable thermal properties and efficient coupling to standard communications fibre. The fibre laser, first demonstrated by Southampton University, has shown up to 50% overall light-to-light efficiency, and can be mode-locked and Q-switched. Such lasers use fibre components such as mirrors and λ-selective couplers (to separate the pump from the signal), and are examples of integrated fibre components. Other components can also be used, for example polarizers, and other configurations such as amplifiers also need such components.

Amplifiers

Fibre amplifiers can be made by using the doped fibres used for lasers, and these offer better performance than many alternatives because of the efficient and low reflectivity coupling to the telecom fibre, and possibly also because they filter out pump noise. Amplification can also be achieved by using the fibre Raman effect with at least equal performance, and with the Brillouin effect, though this has very narrow linewidth. Fibre amplifiers in general appear likely to be important in wideband and multiterminal communications and work on them around the world is growing.

Second harmonic generation (shg)

It was observed about two years ago that prolonged exposure of a standard fibre to high-power infrared light resulted in the growth of a $\chi^{(2)}$ in the fibre and the conversion of a proportion of the input into the second harmonic. This was very surprising because the fibre and the glass of which it is made are nearly perfectly isotropic, which forbids a finite value for $\chi^{(2)}$. The mechanism is still not fully understood; but, although the shg conversion efficiencies achieved so far are not impressive in themselves, there is hope that a full understanding would lead to useful devices, both for shg and for electro-optic modulators that also depend on $\chi^{(2)}$.

Kerr effects

If a high enough power is propagating in a fibre, the refractive index is altered slightly by the $\chi^{(3)}$ coefficient of silica and this can then be used in conjunction with some other fibre feature, such as dispersion, interferometers or gratings to produce power-dependent behaviour. This can then give switching, pulse compression, reshaping and other useful functions. The coefficient is not large, but it is fast (less than 10^{-13} s) and this gives attractive performance for very fast devices. Furthermore, the light is not absorbed and this gives durability and in conjunction with the low loss of fibre components this makes it possible to assemble more complex structures. The shortest pulses of any kind, about 10 optical cycles, ever produced (not counting individual particles) have been produced using nonlinear fibre pulse compressors.

The $\chi^{(3)}$ coefficient can also be used directly to make an electro-optic modulator (though operating voltages are rather high) and for shortening the pulses from mode-locked lasers, the mechanism for which is complex, but was originally (generally no longer) thought to be related to solitonic effects, which involve the interaction between the nonlinear coefficients and the fibre dispersion.

Soliton propagation

These solitons are stable optical pulses, that is actively stable rather than just undisturbed, that can propagate undispersed for distances limited in practice only by attenuation. Their usefulness for signal propagation has been much discussed but is still disputable, but they can improve the behaviour of the fibre logic devices mentioned above by 'pulling through' the power in the tails of pulses that would otherwise be misdirected, and this may be as important. They and other fast-pulse techniques may be important for very high capacity systems.

Conclusions

The development of optical fibre components has proceeded rapidly from communication fibre technology to generate many new and powerful devices that enable more complex frequency-selective systems to be built economically and open up new possibilities in high-speed and high-capacity communications.