OPTICAL AMPLIFIERS - A TELECOMMUNICATIONS REVOLUTION

Until recently, optical telecommunications networks relied on electrical amplifiers to boost optical signals which had suffered losses either after transmission over long distances, or by division between multiple subscribers. As a result, optical fibres were essentially used as point-to-point optical conduits and were designed specifically for a given data rate and format. Moreover, little use of the extraordinarily-wide optical window could be made, since if multiple optical channels were employed, they had to be demultiplexed into their constituent wavelengths and electrically amplified separately. Despite this, optical fibres now occupy some 60% of trunk networks in the developed countries.

Optical amplification has been known since the first laser and optical telecommunications since the early 70's. Why then did it take so long to develop the obvious missing component, the all-optical amplifier? Although the need was recognised, early research focussed on injection-laser diode amplifiers based on III-V technology. Although considerable progress has been made, diode amplifiers suffer from a number of disadvantages, the most obvious being their geometric incompatibility with optical fibres. This leads to poor coupling losses and hence a degraded noise figure, as well as great difficulty in suppressing feedback reflections. However, perhaps the greatest disadvantage is their short carrier lifetime of around 1ns, which limits maximum modulation rates to only a few GHz, in addition to causing severe crosstalk between channels of different wavelengths.

In 1987 the idea of doping the optical fibre itself with rare-earths to produce an amplifying fibre first emerged at Southampton University. It transpired, by extraordinary good fortune, that erbium exhibits strong gain in the preferred telecommunications wavelength window at 1.55μm, in addition to possessing a very long excited-state lifetime of around 10ms. As a consequence of this and of the fibre geometry which allows a pump beam to be tightly confined within the rare-earth-doped core, gains as high as 40dB can be obtained with a few milliwatts of pump power from a diode laser.

The erbium-doped fibre amplifier (EDFA) simply consists of a few metres of optical fibre doped with some hundreds of parts per million of erbium in the core. Pump light is introduced by means of a wavelength-multiplexing four-port fibre coupler. The amplifier is fusion-spliced between the incoming and outgoing fibres, thus eliminating any reflections and allowing high gain to be achieved without problems of laser oscillation. Furthermore, being circularly symmetric, the fibre amplifier exhibits no polarisation sensitivity, unlike the diode amplifier. Perhaps most importantly, the EDFA has an emission cross-section some 10^4 times lower than the diode amplifier which means that 10^4 times more excited-states are required to achieve the same amplification. Whereas at first sight this may appear to be a disadvantage, the effect is to provide a large reservoir of excited-states in the amplifier which virtually eliminates any form of signal distortion and interchannel crosstalk, except at frequencies so low as to be of little interest to telecommunications. Thus the amplifier saturates gracefully and can be used with multiple wavelengths simultaneously. Even when saturated by the signal, undistorted gain compression is experienced and under these conditions EDFAs are found to have approximately quantum-limited efficiency, i.e. one signal photon is generated for every pump photon absorbed.

Development of the EDFA worldwide has been astonishingly rapid. The noise performance is found to be virtually quantum-limited and this permits hundreds of amplifiers to be cascaded without significant signal degradation. The fibre transmission medium can thus be made effectively lossless and laboratory experiments to date have indicated that trans-oceanic distances can readily be traversed. Furthermore, lossless splitting of the signal between subscribers is possible by subsequent reamplification of the signal and it has been demonstrated that several million subscribers can be served with the aid of just a few optical amplifiers. Such optically-amplified systems are truly transparent to optical wavelength, data rate and code and can thus be upgraded in the future by replacing the electrical terminals.

Only four years after its initial invention, commercial EDFAs are now offered by more than 30 companies, which must be close to a record for development of a new technology. The impact of the EDFA is being felt within a number of allied technologies, such as non-linear optical fibre switching and routing, where the amplifier provides the ability to generate high-power pulses sufficient to access the non-linear regime. Thus soliton transmission, once a theoretical dream, is now a reality and offers the possibility of overcoming the dispersion of the fibre, as well as its loss. Thus we can look forward to the possibility of trans-oceanic fibre links operating at 10Gbit/second or more using entirely optical amplifiers. Perhaps in the future we may also expect undersea all-optical switching and routing. These developments are expected to shift future international telecommunications traffic from satellites to undersea fibre routes. Thus the development of the EDFA has removed a barrier which promises to allow optical telecommunications finally to reach its full potential.

(Note : the talk itself will concentrate also on the physics of the amplifier as a component, and describe its internal workings).