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UCOL PROJECT: RECENT ADVANCES

D. Capolupo, S. Forcesi, E. Neri, F. Testa
ALCATEL FACE Research Centre - Via Nicaragua 10, 00040 Pomezia, I
Tel.: +39 6 912851, Fax: +39 6 9108066, Telex: 613340
O.J. Koning, A.C. Labrujere, J.P. Bekooÿ
PTT-Research Neher Laboratories - St. Paulusstraat 4, 2264 XZ Leidschendam, NL
Tel.: +31 70 3325602, Fax: +31 70 3326477, Telex: 31236 ml nl
M. Eisenmann, B. Hillerich, E. Weidel
DAIMLER-BENZ AG Research Center, Wilhelm-Runge Straße 11, 7900 Ulm 31, D
Tel.: +49 731 5052065,Fax: +49 731 5054103, Telex: 72194-0
H. Schmuck, G. Veith
SEL ALCATEL Research Centre - Holderäcker Straße 35, 7000 Stuttgart 31, D
Tel.: +49 711 8692168, Fax: +49 711 8692185, Telex: 72194-0
L. Reekie
UNIVERSITY of SOUTHAMPTON / Optical Fibre Group - Highfield, Southampton S09 5NH, UK
Tel.: +44 703 595000, Fax: +44 703 671391, Telex: 47661
E. Carrapatoso
INESC - Largo Mompilher 22, Apartado 4433, 4007 Porto Codex, P
Tel.: +351 2 321006, Fax: +351 2 318692, Telex: 23023 INESC P

ABSTRACT

UCOL (which stands for Ultra-wideband Coherent Optical LAN) is a system aiming to provide integrated support of narrowband and broadband services (data, voice and video) to the need of specific localized communication environments. This report presents the advances of UCOL after the first year of the realization phase. A number of modifications have been made since the original plan, allowing the project to be feasible applying current technology. The new approach to the physical layer is described together with the already developed optical subsystems; finally the UCOL access protocol is reported.

1. INTRODUCTION

The UCOL project builds on a feasibility study which has underlined the potential of coherent optical techniques in the context of broadband local area networks. This study also indicated that a global approach, which addresses both optical and networking aspects, was necessary to design a network capable of supporting heterogeneous narrowband and broadband services.
This report describes the advances made after the first year of the realization phase. In Section 2 the optical coherent multichannel transmission system of the UCOL network is described, together with the changes introduced with respect to the previously reported scheme [1]. Section 3 presents a review of the main experimental results obtained in developing the optical subsystems. Finally, Section 4 discusses the current status of the access protocol development.

2. SYSTEM DESCRIPTION

UCOL is a network interconnecting a large number of Network Interfaces (NI), i.e. a Transmitter/Receiver pair; the link among NIs is performed by means of single mode fibres operating within the 1.5 µm window, which are all connected to a central passive transmissive star, that acts as frequency multiplexer as well. All the interfaces are able to communicate over a set of 20 FDM optical channels, frequency locked to a common reference source, each one realizing a 150 Mb/s information channel upon which information is carried as ATM cells that are time division multiplexed on the channel. The available system gain allows a main configuration offering a connection, over a star radius of up to 10 km, for more than 1000 NIs. Each NI is directly connected to the central star in order to avoid additional losses due to local splitters/combiners. The BER of the physical channel has been fixed at 10^{-6}: this increases the receiver sensitivity and makes it less vulnerable to adjacent channel interference. The channel quality is improved with Forward Error Correcting (FEC) techniques, which restore the BER to a value better than 10^{-12}. The modulation scheme is the Differential Phase Shift Keying (DPSK) with a transmission gross rate of 300 Mb/s. The receiver is based on a polarization diversity scheme as it avoids the need of fast adjustment to the channel's states of polarization (SOP).

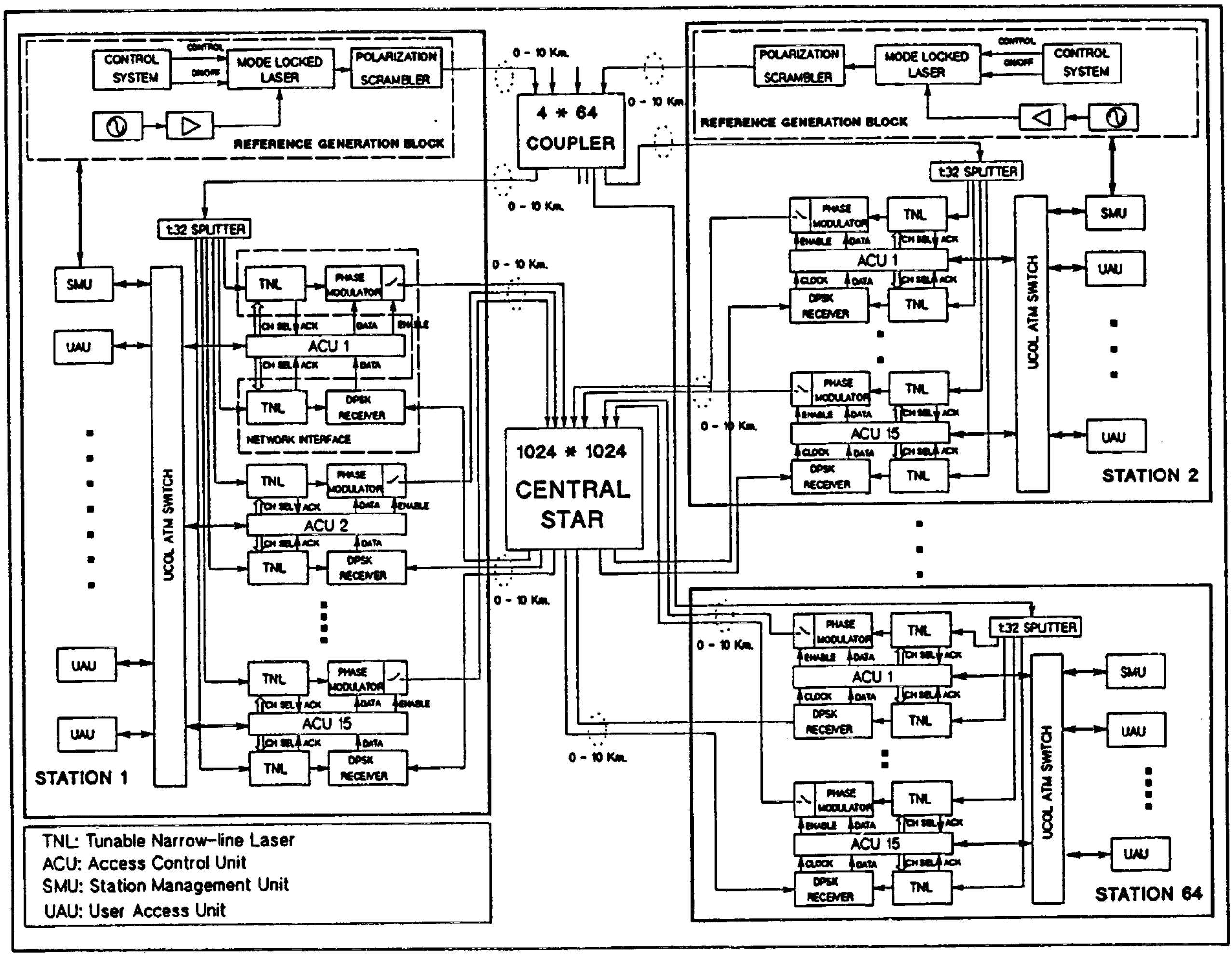

Figure 1 - UCOL system block diagram

The UCOL optical hardware is constituted (Fig. 1) of a number of Stations (up to 64), each one including up to 16 NIs, a central passive star and an auxiliary central coupler used for the distribution of the frequency reference. A Reference Generation Block (RGB), that provides all transmitters and receivers a frequency reference constituted by a set of equally spaced lines, is

located in one of the stations: this reference comb is distributed by means of both the additional central coupler and the power splitters located in each station.
The RGB is composed of a mode-locked laser, driven by a microwave signal (at 3.6 GHz, corresponding to the comb lines spacing), followed by a polarization scrambler to enable SOP insensitive detection of the reference lines.
The fundamental optical component within each NI is the Tunable Narrow-line Laser (TNL), which is used both as carrier generator in the Transmitter and as local oscillator in the Receiver. It can be locked, with a proper offset frequency, to any of the reference lines provided from the RGB by means of an Automatic Frequency Control (AFC) scheme. In the transmitter the TNL is followed by a phase modulator and isolation switch; the latter is used to disconnect the transmitter from the network during its idle state. The receiver is composed of a balanced polarization diversity optical front-end, fed by both the local oscillator signal and the incoming data signal, a low noise preamplifier and a delay-line DPSK demodulator. The connection of the external world to the NI is depicted in Fig. 2, where the UCOL station architecture is shown. User terminal equipments access the network through dedicated interfaces called User Access Units (UAUs). Each station provides network access to 480 UAUs divided in 15 groups of 32 UAUs each. The set of the 480 UAUs and the 15 GAUs (Group Access Unit) forms the station user interface. The station interface towards the network consists of 15 Access Control Units (ACUs), performing the access protocol to the shared resources and 15 NIs that realize the physical optical link to the star centre.
In consequence of natural evolution of the system concept and following the evaluations by CEC experts, three major changes were introduced in the optical hardware:

- centralized reference generation block
- double star configuration
- substitution of the Optical Phase Locked Loop (OPLL) by an Optical Frequency Lock Loop (the above mentioned AFC).

All of these modifications allow a significant simplification of the hardware needed for the reference recognition and locking mechanism and avoid the questionable implementation of the OPLL. Moreover two promising optical devices, the Erbium-doped fibre amplifier and a semiconductor laser amplifier acting as phase modulator and switch, have been introduced in the project in order to further enhance the system gain and hence the overall network capacity.

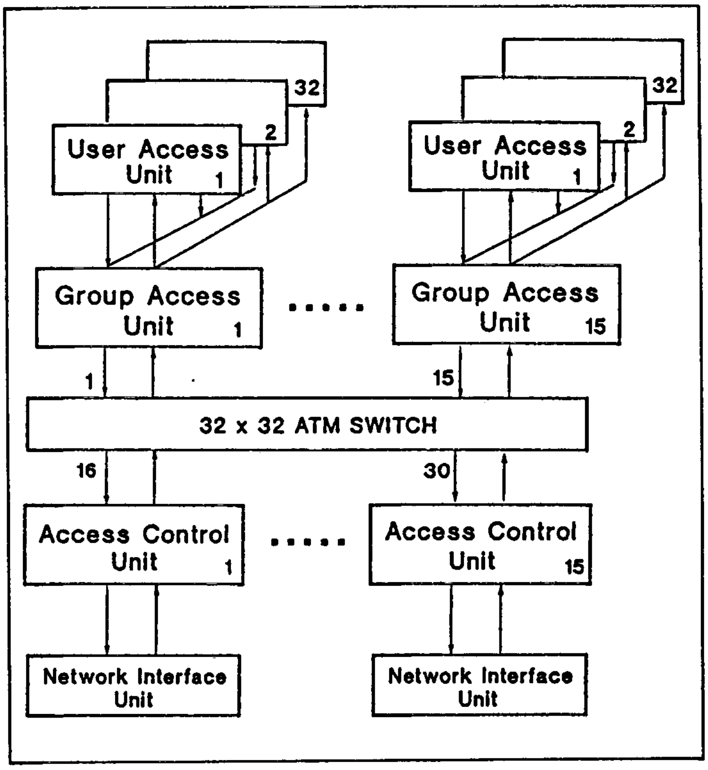

Figure 2 - UCOL station architecture.

3. EXPERIMENTAL RESULTS

Presently, all the basic optical building blocks of the system are being developed. For some of them, being near completion, a description of both the working principle and the achieved results are presented.

3.1 Reference frequency generator

In the UCOL-system all the NIs are locked in frequency to a centrally distributed optical reference comb provided by the RGB. This comb, consisting of a number of equidistant lines, can be generated by mode-locking of a grating extended semiconductor laser. Mode-locking is the process of phase-locking of successive longitudinal external cavity modes by gain modulation at a frequency resonant to the Free Spectral Range (FSR) of the cavity. The spectrum of the mode-locked laser consists of a cluster of equidistant lines (spaced exactly by the modulation frequency) in a bell-shaped envelope. The extension of the comb is limited by the gratings spectral filtering.

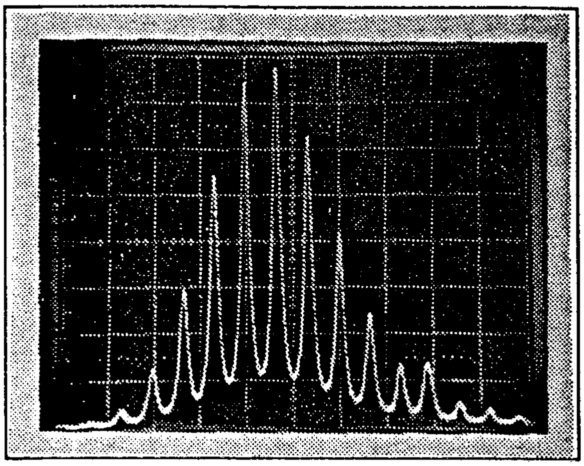

Figure 3 - Scanning Fabry-Perot interferometer trace showing the mode-locked laser output spectrum. Horizontal scale: 5.8 GHz/div.

The laser used in the present experiments is composed of a Fabry-Perot (FP) laser chip AR-coated at one side, a collimating GRIN-lens and an external diffraction grating. The FSR of 3.6 GHz corresponds to an external cavity of about 4 cm. The laser diode is mounted on a micro-strip printed circuit, which is optimized for broadband frequency response up to 4 GHz. The central operating wavelength is at 1.53 µm and the laser can be tuned discontinuously over 70 nm. A continuous tuning range of 40 GHz was achieved by tilting the grating accompanied by a proper axial translation. The power per comb line equals approximately the laser CW power divided by the number of lines, and has a value of about -16 dBm for 9 comb lines. In Fig. 3 an output spectrum of the mode-locked laser is visualized on a scanning FP interferometer. Several comb lines are visible within a Gaussian-like envelope. A more extensive comb may be generated by using a grating with a lower resolving power. From more detailed experiments the linewidth of the individual comb lines was determined to be smaller than 1 MHz. Frequency-locking experiments have been performed by combining the mode-locked laser output with a tunable laser. During locking, the relative frequency stability was determined by the performance of the AFC circuitry only. Fig. 4 presents a sequence of three FP-traces while the tunable laser was locked relative to three different comb lines. The locking performance during continuous tuning of the reference comb was also studied. The laser remained stably locked to the same line while tuning the comb over 40 GHz.

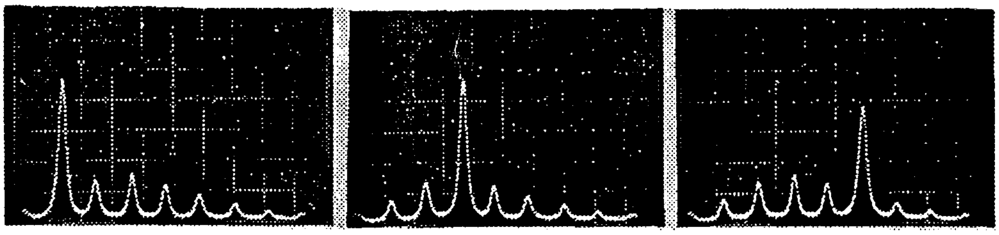

Figure 4 - Spectra showing a tunable laser locked to three different comb lines, as measured on a Fabry-Perot interferometer. Horizontal scale: 3 GHz/div.

3.2 Fibre-based polarization diversity optical hybrid

The fibre-based optical hybrid for the UCOL polarization diversity receiver is shown in Fig. 5. It consists of a 3 dB coupler and two TE/TM splitters. To achieve low losses, all couplers are made of standard single-mode fibres by fused biconic taper coupler technology. The essential part of the hybrid is the TE/TM splitter. Its operation is based on the polarization dependence of the two lowest order modes interfering in the fused region.

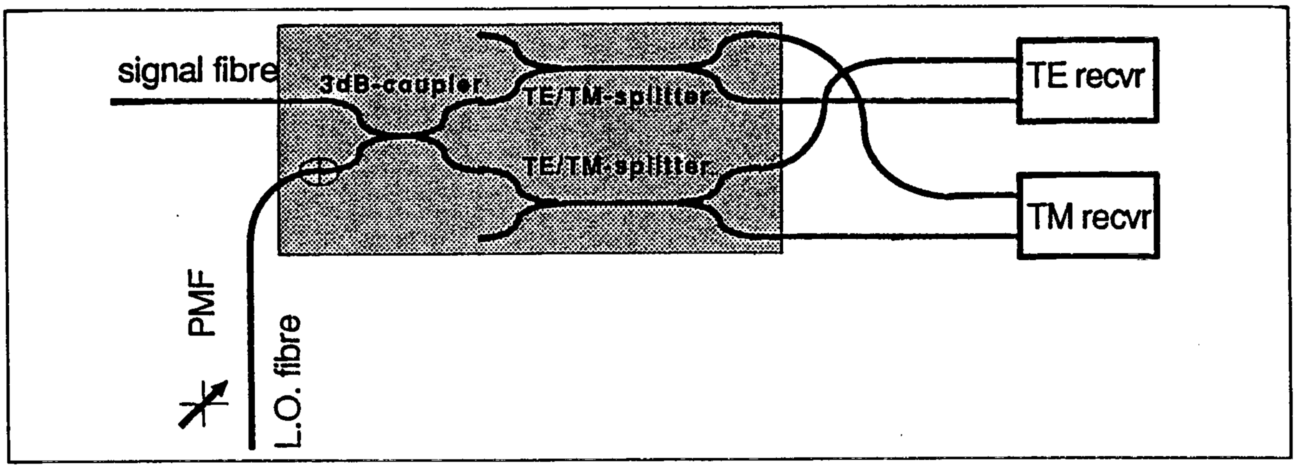

Figure 5 - Schematic diagram of fibre-based polarization diversity hybrid.

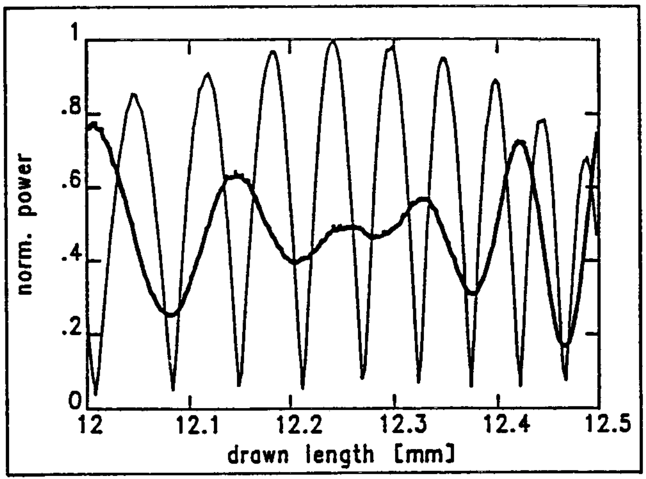

Figure 6 - Measured average output power (thick line) normalized to the input power, and degree of polarization (thin line) during the drawing of the TE/TM splitter.

Fig. 6 shows typical data measured during the drawing process. Using a polarization modulator at one input fibre [2], the mean power (thick line) and the degree of polarization (DOP) are recorded on-line. The highest relative maximum of the DOP provides the criterion for stopping the drawing process. For an optimum TE/TM splitter, however, this condition is not yet sufficient, but the relative maximum of the DOP has to coincide with the maximum of the envelope curve of the DOP. This has been achieved by a fine tuning of the manufacturing process. In Fig. 7 the measured extinction ratio for both output fibres versus wavelength is shown. The operating wavelength is 1555 nm. The minima of both curves are nearly coincident, thus indicating a well optimized manufacturing process. Before optimization these minima were about 8 nm apart, which deteriorates the extinction ratio substantially. The reproducibility of the manufacturing process is satisfactory. For instance, the center wavelength is reproducible within ±3 nm. The spectral width for an extinction ratio of -15 dB is 17 nm. The excess losses are very low; typical values for a complete hybrid are 0.5 dB. In order to avoid a sensitivity penalty in the polarization diversity receiver, the signal SOP has to remain unchanged between the 3 dB coupler and the TE/TM splitters. Furthermore the power of the local oscillator has to be equally distributed to all output fibres. To ensure this, in an earlier version with 3 dB coupler and TE/TM splitters in separate housings [3], not only the fibre connecting the local oscillator but also the fibres between the 3 dB coupler and TE/TM splitters had to be polarization maintaining fibres (PMF) being spliced to the standard fibres in correct orientation. In the new integrated design, two TE/TM splitters and a 3 dB coupler are integrated in a single package, thus avoiding the PMF in between the couplers. At first, two TE/TM splitters are separately drawn; then a 3 dB coupler is made from two of the output fibres; finally the completed hybrid is packaged in a common housing. The coupling of the fibre pigtails to the monolithically integrated photodiode pairs is performed by a flat pre-aligned coupling technique [4]. Owing to angled end-faces of the fibres, back-reflection to the local oscillator is as low as -55 dB.

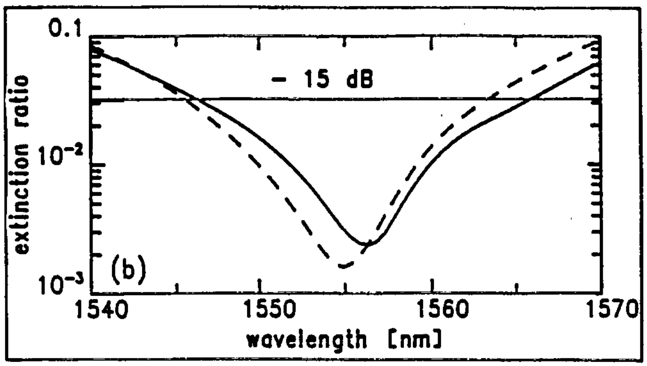

Figure 7 - Measured extinction ratio of a TE/TM splitter vs. wavelength. Full line: output fibre 1; dashed line: output fibre 2.

3.3 Tunable Fabry-Perot type optical filter

In the original concept of the UCOL optical hardware, each station was equipped with a regeneration block, both to recognize the (un-modulated) central reference line among the set of FDM modulated channels and to regenerate it by means of filtering followed by optical amplification. As described in Section 2 this concept has been modified and the new approach, in which all the stations are fed with the reference comb lines by means of a separated network, does not foresee the use of a tunable optical filter to select the central line. Nevertheless, due to the importance of this advanced optical component in the context of multi-channel optical communication systems, it has been decided to carry on with the development of a laboratory prototype.

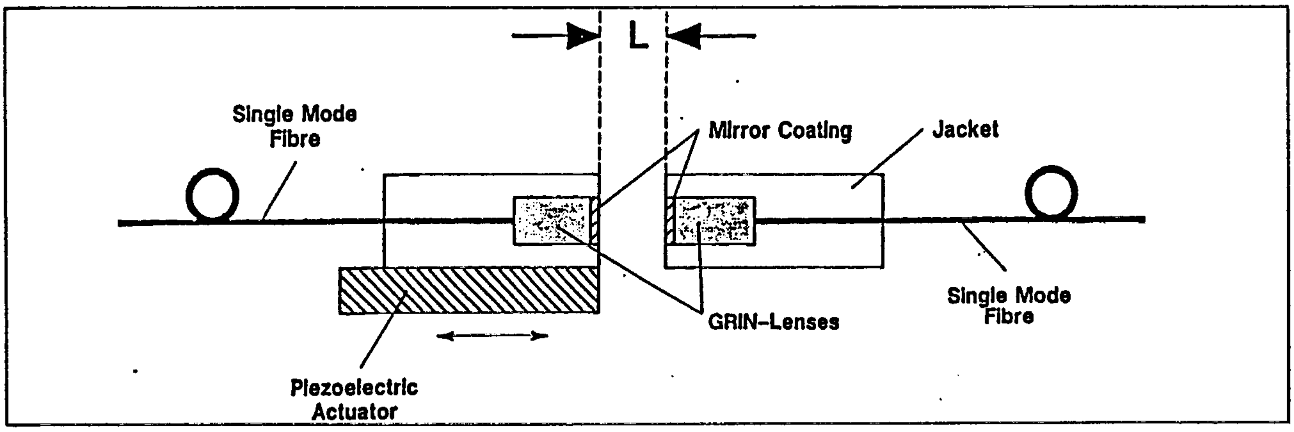

Figure 8 - Set-up of fibre-pigtailed GRIN-lens Fabry-Perot optical filter.

The realized narrowband tunable optical filter is based on a GRIN-lens Fabry-Perot resonator (Fig. 8). The facing surfaces of the two 0.25 pitch GRIN-lenses were polished to obtain a flatness better than $\lambda/200$ and subsequently coated with a high reflectivity coating (R=97.8%). After pigtailing the GRIN-lenses were mounted to form a FP resonator. The device was tested to characterize its performance as tunable filter. Tunability was accomplished by the use of piezoelectric stacks. For a FSR of 42 GHz (the initial UCOL specification) corresponding to 3.6 mm resonator length, the measured device Finesse (F) was extremely high (F=128±5) corresponding to a filter bandwidth of 350 MHz. The overall device insertion loss, comprising throughput loss, mirror loss, fibre coupling loss, misalignment loss, tuning loss, imperfect mirror flatness and multipass loss, was measured to be 5.2 dB. Being the performances of the FP filter critically affected by any misalignment, the device has to be temperature stabilized. The device was also tested in a large interval of resonator lengths ranging from 0.5 mm to 200 mm, maintaining good performance with respect to total loss and Finesse as shown in Fig. 9.

For its versatility and insensitivity to polarization, this device is very promising both as a filter in high density WDM systems and as a compact measurement instrument.

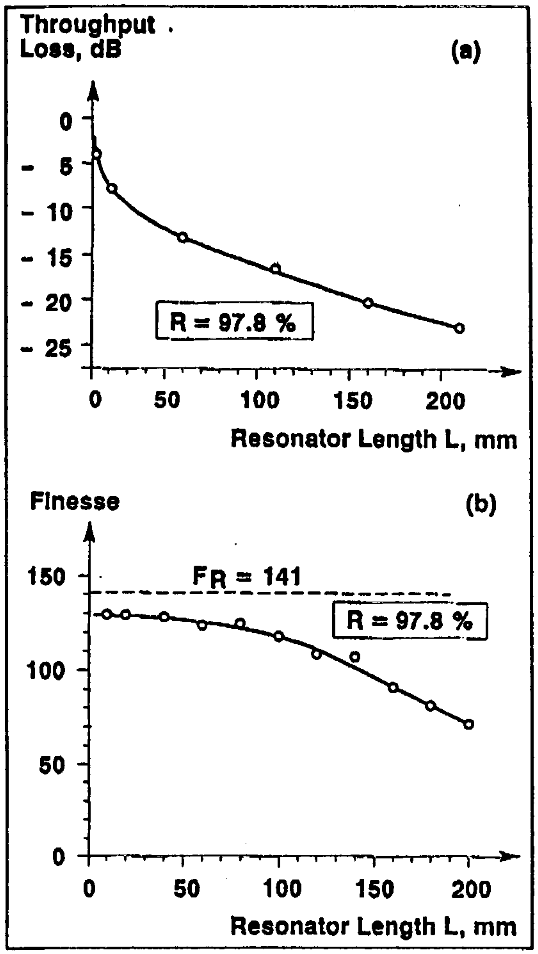

Figure 9 - Tunable optical filter: a) throughput loss and b) Finesse of long resonator GRIN-lens FP filters (L 200 mm)

3.4 Erbium-doped fibre laser

The UCOL project foresees the use of tunable narrow-linewidth lasers (TNL) acting as both transmitter and local oscillator sources, as described in Section 2. As monolithic laser sources matching the UCOL requirements were not available, preliminary investigations on alternative solutions have been carried out, one of which aims to provide a working model of a tunable Er^{3+}-doped fibre laser operating around 1.535 µm. This device will be pumped by a semiconductor diode laser operating at 980 nm and will have an output power in excess of 0 dBm (1 mW) across its tuning range.

A laboratory prototype device has been constructed with an output power of 7 mW for only 15 mW of pump power launched into the fibre. The normally broad free-running linewidth of

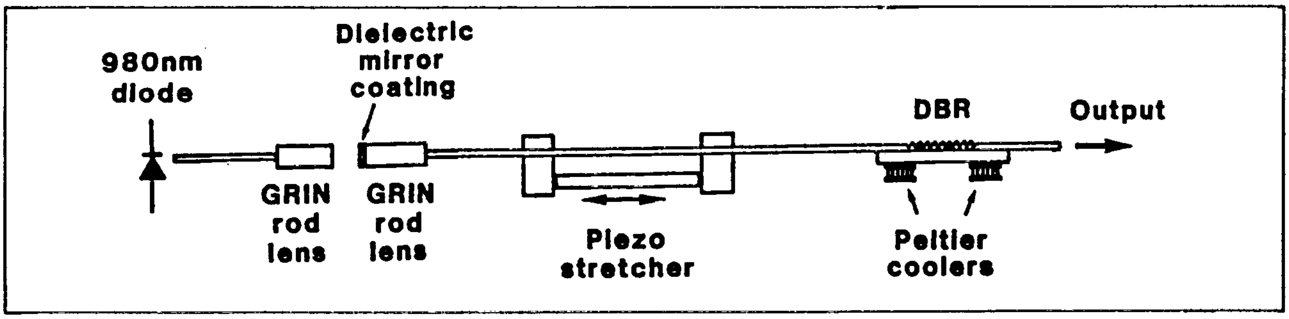

Figure 10 - Erbium-doped fibre tunable laser.

the fibre laser is narrowed by incorporating a fibre grating as an output coupler. This device (Fig. 10) consists of a diffraction grating which is either physically etched or holographically exposed into the core of a doped fibre using ultra-violet light. This grating then acts as a narrowband reflector which is capable of forcing the laser to oscillate in a single longitudinal mode. The laser frequency can be tuned by either temperature tuning or stretching of the fibre grating using a piezo-electric element. Gross tuning (~40 GHz) has been achieved; continuous tunability can be maintained by simultaneously stretching the doped fibre itself.

To date, a laser operating on two adjacent modes has been demonstrated using a short, low resolution fibre grating. A longer grating having a smaller reflection bandwidth will be incorporated into the final device to obtain single longitudinal performance.

4. NETWORK ACCESS PROTOCOL

The TDM access on the same channel has to be regulated by a suitable protocol which shares the available bandwidth among users. The definition of such a protocol, the Distributed Queue Access Control (DQAC) protocol, which is independent of the characteristics of the user services, capable of coping with synchronous and asynchronous, connection oriented and connectionless traffic, has been the primary network aspect faced up in the first phase of the UCOL project. The distinctive features of the protocol will be described.

DQAC is based on the following principle: requests for access are forwarded through the network according to the number of cells held in the local queues, the access control being a distributed function since every station, collecting all the requests, performs the scheduling algorithm on the same information base and univocally governs the channel access. This translates into a frame based transmission scheme that implies:

- a time reference is cyclically distributed to all the stations,
- each station knows in advance where to put its data cells within the frame,
- each station anticipates the transmission of its data cells by an amount of time equal to the propagation delay along the fibre.

4.1 Protocol base

In Fig. 11 the adopted frame structure is shown: it is 1 ms long and is made up of three parts: Frame Header, Queue Status (QS) field and Information field for a total length of 300,000 bits. The frame header is generated by one of the stations: if for any reason this station should go down, an appropriate procedure is defined so that a new station starts generating the frame synchronism. The QS field contains 64 Control Slots, one for each station, according to a fixed transmission order: the first slot is reserved to station 1, the second to station 2 and so forth. The QS field provides all stations with the information they need to decide which data slots they will use. The information carried by the QS field of frame T is used to arbitrate the access to the Information field of frame T+1: so, when a new frame starts, every station already knows (according to a predefined algorithm executed by all stations) which slots of the Information field will be used in that frame. The Information field is divided into 426 Data Slots, each containing one ATM cell.

It is now possible to describe the QS based access mechanism. For each station the relevant Control Slot indicates the number of cells that are held in each of the five priority queues (P0 to P4). The slot allocation mechanism is quite simple: after all the stations have received the QS they begin to elaborate it concurrently. Starting from the highest priority (P0), slots are assigned, one to each transmitting station, until every station has obtained a number of slots equal to the number of cells queued. Only after all slots of a given priority have been assigned, slots of the next priority undergo the allocation procedure.

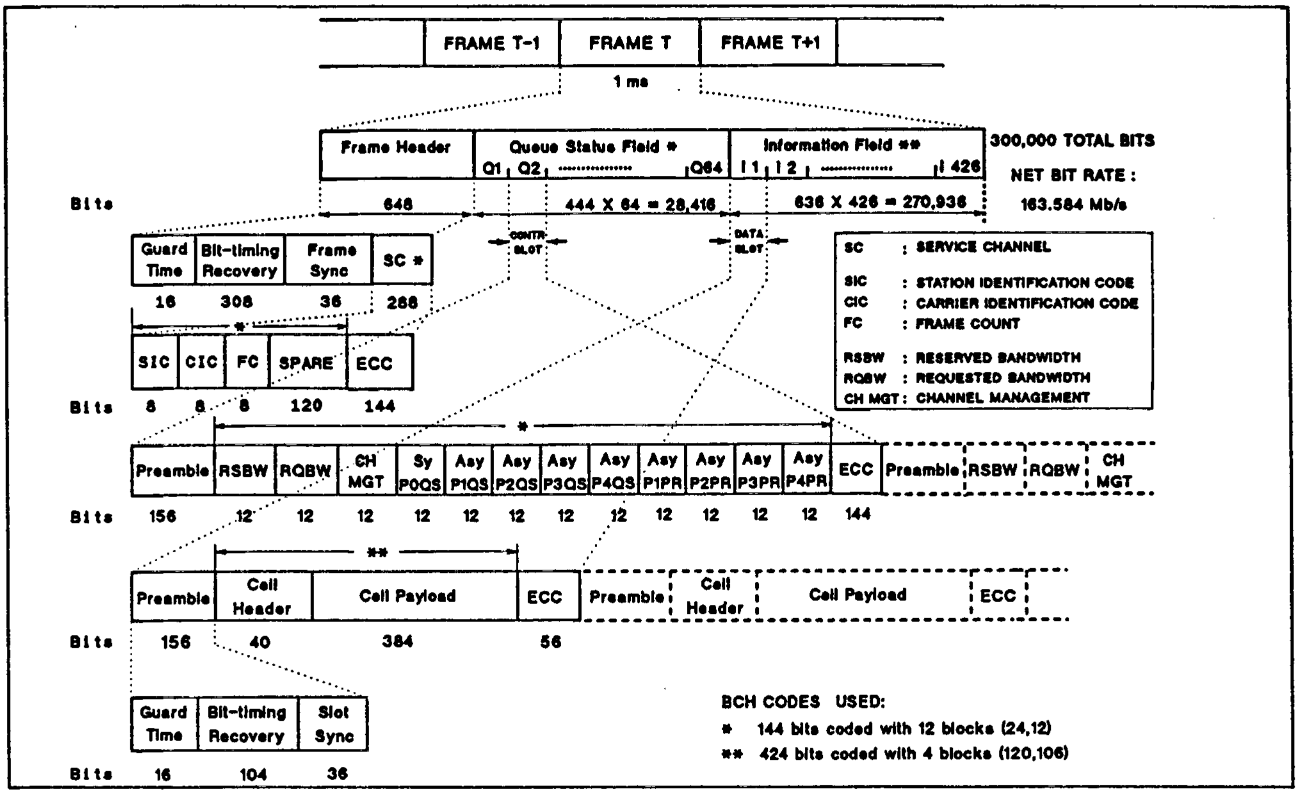

Figure 11 - Frame structure.

4.2 Protocol enhancements

In order to increase the efficiency over each optical channel two major enhancements have been introduced, namely the bandwidth reservation mechanism and the prediction mechanism; both are explained hereafter.

Within UCOL, synchronous traffic is handled as traffic with priority P0, while priorities P1-P4 are used for asynchronous traffic. Since synchronous traffic requires that the same number of information cells be transmitted in the unit of time, a mechanism must be provided that reserves a given number of slots on each frame, for all the duration of the connection. In the Control Slot of each station, two fields have been introduced: RSBW (ReServed BandWidth) and RQBW (ReQuested BandWidth). When a station requires bandwidth for a new (synchronous) connection, it fills the RQBW field of its Control Slot with the number of cells it intends to use. If its request is satisfied, starting from the next frame, its RSBW field is incremented by the number previously written in RQBW, while RQBW is set again to zero. When a connection is dropped, the RSBW field is decremented by the number of cells (per frame) that the connection was using.

UCOL must also handle traffic generated by bursty sources. Although, due to statistical multiplexing, load fluctuations may be smoothed, each individual source may generate peak loads during relatively short periods, thus producing a high peak to average load ratio. The basic DQAC protocol does not react quickly to sudden changes of bursty traffic and that may lead to bandwidth waste; in fact, all cells must wait, at least, for the transmission of the QS to request slots for them in a future frame, even if the current and the next frame are not fully occupied. This fact, not only causes unnecessary delay but, may also lead to congestion situations if, meanwhile, too many cells have arrived. Two enhancements, which improve the protocol performance, were evaluated: the prediction concept and the exhaustive scheme. These enhancements enable the reservation of slots, that would otherwise be wasted, for the transmission of recently generated cells. If these reserved slots are in fact used, there is a gain; if they are not used, there is no loss relatively to the basic algorithm. The prediction concept relies on the request of bandwidth in advance for the load that is predicted for the near future: a number of slots, calculated through a prediction method, will be requested to transmit cells that will arrive in the following frames. Although accuracy is highly desirable, two other characteristics shall be taken into account in selecting the most suitable algorithm: simplicity and speed. Three methods that might comply with such antagonistic requirements were simulated, one of them proving to be better than the others in nearly all situations. The other enhancement considered is the exhaustive scheme. Basically it consists of the exhaustive allocation of all available slots in a frame. Two alternatives were simulated: Exhaustive allocation using only the usual QS requests and Exhaustive allocation using the prediction requests. All the enhanced versions have proved to be a far better solution than the original protocol as far as delay is concerned. Figure 12 shows a substantial reduction of the delay which could be expected. The best solution, in terms of performance, among all enhancements simulated, is the exhaustive scheme when used together with the prediction concept. It retains all the characteristics of the prediction mechanism, and, in addition full allocation of the bandwidth is always guaranteed.

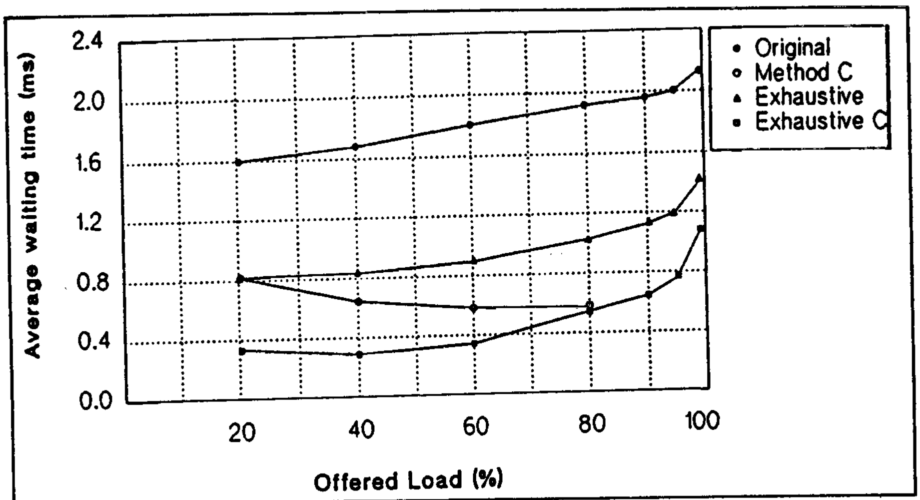

Figure 12 - Average waiting time vs. offered load: basic DQAC (Original), original with prediction (Method C), exhaustive, and exhaustive with prediction (Exhaustive C).

CONCLUSION

The architecture and the development of the physical layer of the coherent optical multichannel UCOL network have been presented. The current state of the research on some of the optical subsystems has also been reported together with the the definition of the network access protocol. Further details on the progress of the hardware development will be provided at the Exhibition organized by the UCOL Consortium for the ESPRIT Conference 1990.

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