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The RACE Program of the European Communities

J.F. Blackburn

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The background of RACE – the program for R&D in advanced communications technologies for Europe – and progress in the technologies it embraces are discussed. Those technologies include: switching, transmission, customer access, terminal and display, and coding. Keywords:

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THE RACE PROGRAM OF THE EUROPEAN COMMUNITIES

Introduction

~~In October, 1984, in Luxembourg,~~ the industry ministers of the European Community governments adopted two recommendations directed toward a telecommunications strategy ~~(ESN 39-3:122-23)~~. All member governments would ensure that national telecommunications administrations consult before introducing new services. Under the recommendation, new services put into operation from 1985 onwards would have to conform to standards then being laid down by the developing network of European standards bodies. The Community granted 6 million European Currency Units (ECU's) ($7.44 million [1 ECU = $1.24]) to these bodies for a 2-year program (1984-85) to define and certify European norms in telecommunications. Equipment other than terminals would have to conform to common standards from 1986 onwards.

The second recommendation would open bidding to all member states for procurement of conventional terminals and telematic terminals.

Subsequently, on December 17, 1984, the Council of Ministers of the member countries agreed on the main elements of a Community telecommunications policy including the objective of developing advanced telecommunications services and networks by actions on the Community level.

On 25 March 1985 the Commission submitted to the Council of Member states a proposal for a Community Research and Development Program in telecommunications technology called R&D in Advanced Communications-technologies for Europe (RACE).

The proposal led to a 12-month RACE Definition Phase covering:

- Development of an integrated broadband communication (IBC) network reference model
- Definition of the IBC terminal environment
- Future applications assessment.

The definition phase was carried out in 1986, and was to be followed in 1987 by the beginning of a 5-year research program. Funds, however, were not approved in time for a start of the program in 1987. However, a request for proposals was issued in June 1987, and a budget of 550 million ECU for a 5-year period was approved on December 14, 1987. Mr. Spyro Konidaris, Directorate General XIII said on February 22, 1988, that there is a possibility of recovering a further 250 million ECU from the earlier request which did not get approved, for a total of 800 million ECU.

In response to the proposal request of June 1987 about 100 proposals were received and 50 projects were approved.

The RACE program is a community initiative to explore the impact of advanced technology on future communications systems in Europe. The main thrust is toward integrated broadband communications (IBC) for Europe in the 1990's and beyond. The work plan is based on the following considerations:

- The target date for EC-wide commercial introduction of IBC in Europe is 1995.
- The introduction of IBC is to build on the evolution of Integrated Services Digital Network (ISDN).
- Standardization of the IBC is to be in step with plenary meetings in 1988 and 1992 of the international standards body, CCITT.
- IBC introduction requires the coordinated development of applications, networks, and enabling technologies.

The program is concerned with:

- The identification and classification of the services which might be carried by an IBC Network
- Reference models and scenarios for the different parts of the IBC Network in a logical order related to the overall Network Reference Model
- IBC system-related issues
- The key technologies relevant to the introduction of the advanced communications systems.

This report will concentrate on the technologies. These technologies include switching, transmission, customer access, terminal and display, and coding. These will be discussed in the order given based on work carried out in the definition phase in 1986.

Switching Technologies

Project 1024

Project 1024 considered the internal architecture of the IBC system and the impact that the subscriber access and the network access have on it in order to reach some conclusions on what might prove to be the preferred architecture. This included consideration of broadband

Dr. Blackburn is the London representative of the Commerce Department for industrial assessment in computer science and telecommunications.

and narrowband and relationship between these services and the internal functions. Various levels of integration were considered, ranging from a switch for each of four classes of service to one integrated switch for all services. The study included space switching, synchronous time division multiplexing (TDM), asynchronous TDM, and optical switching, resulting in a large number of possible internal configurations.

The range of options considered for subscriber access included: synchronous TDM for all channels; asynchronous TDM for all channels; and hybrid solutions, possibly involving dynamic rearranging. A similar range of options was considered for the network access.

Each option considered had a different impact on the internal architecture of the switch, each coupling well with particular levels of switch integration. It was not possible to recommend a best approach. It was suggested that because of differing constraints in each of the networks and differing evolutionary pressures there may be no "best" approach.

Some indications on architectural issues given by this project were:

- Since it is not clear that TDM (synchronous or asynchronous) techniques will be able to handle 140-Mb/s channels, multiplexed to higher rates, it is likely that there will be a space switch solution to cover distributive services which require such rates. The relative merits of optical and electrical space switching have not yet been evaluated. However, Project 2031 suggests the use of wavelength division multiplexing (WDM) in combination with TDM to resolve the problem.

- No conclusions were reached on the choice between synchronous and asynchronous TDM (from a cost viewpoint) for the dialog-type services which would remain. Multirate TDM as well as asynchronous TDM offers flexible allocation of user channels with comparable architectural overheads.

- Subscriber access and trunk access aspects have been studied in relation to whether video is switched at 34 or 140 Mb/s and whether channels can be dynamically regrouped. Although it is clear that dynamic schemes have the advantage of flexibility and can make better use of bandwidth, no conclusions were reached on whether the advantages outweigh the additional complexity and cost of the exchange termination.

Each of the four switching techniques considered in project 1024 was subjected to a detailed qualitative analysis, under the headings: timing of introduction, network environment, flexibility and sensitivity to changes in the environment, performance, reliability, and service suitability.

Project 2023

Project 2023 is the major proponent of the IBC network using asynchronous time division (ATD) techniques. A network model was produced, based on a simplified network structure. Initial results from the modeling activity indicate that even the stringent delay and delay jitter requirements of voice telephone can be met using ATD techniques. Modeling of an ATD network with a single bearer service showed that it can offer a quality of service required by all kinds of services, including the synchronous services, which fulfills the CCITT requirements and is not less than the quality offered by existing networks. There is no need to define special bearer services for synchronous services. However, since technoeconomic considerations may impose the requirement to make distinctions, alternative solutions have also been considered within this project.

ATD is a technique for the dynamic allocation of network transmission and switching resources, achieved by the transmission of user information in blocks which are identified by an associated label instead of a clock. The project concludes that the ATD technique represents an attractive and viable basis for implementing IBC networks. ATD offers service flexibility through speed, transparency, and economy through accessibility of the total bandwidth by any service. Flexibility allows open-ended service, and implementation technology evolution and design decisions do not have to depend on accurate forecasts of services and their mix. Different switch structures were found to be technologically feasible for bit rates up to 565 Mb/s. In all cases, the switch is organized as a multistage structure of switch elements. The switch elements investigated were: a matrix of buses, a torus of rings, and a high-speed TDM bus. A combination of different technologies (CMOS and high speed) was found to be most appropriate. Common functional blocks such as queues and serial-parallel conversion were identified.

Switching and Multiplexing. Switching technologies considered in the RACE Definition Phase were electronic and optoelectronic switching. In both cases there are major uncertainties as to what data rates will be achieved by what technologies and by when they will be available for application in the network. Currently available electronic space switching technology can handle bit rates up to and beyond 140 Mb/s, and Project 1024 notes that time division multiplexing is a convenient technique for switching broadband channels in the 2- to140-Mb/s range. This comment applies particularly to synchronous time division. For ATD, Project 2023 has demonstrated the feasibility of switching at higher speeds.

Electronic Switching. Three main categories of electronic switching are favored: CMOS, silicon bipolar, and gallium arsenide (GaAs).

- CMOS is favored where high integration levels are desired and where the required operation rates are not too high. CMOS is currently capable of multiplexing 32 in and 32 out lines with 50-Mb/s operation and a power dissipation of 1.6 W. Project 1024 anticipates integrated space switching using 0.5-μm CMOS technology for 34 Mb/s and sizes of 64 inputs, 32 outputs, and 32 expansion inputs with a power dissipation around 0.3 W. No power advantage is seen for CMOS technology over emitter-coupled logic (ECL) for 140-Mb/s operation, however. It is the opinion of Project 2023 that in an ATD switch, a combination of CMOS for the high-complexity functions and silicon bipolar or GaAs for the speed-critical serial parts of the switch, can presently handle bit rates up to 565 Mb/s.

- Silicon bipolar is the only technology which is currently capable of handling data rates up to and beyond 140 Mb/s. Future developments are expected to extend the upper limit of bit rate and to reduce the power dissipation of this technology, which is currently higher than that of CMOS or GaAs. A promising new technology in silicon is the N20 Subilo technology, designed to allow high-speed circuits with high component density. Multiplexing of 140-Mb/s channels into a trunk of 1.1 Gb/s is foreseen as feasible, current state of the art. A further development, up to 2.5 Gb/s, is foreseen by Project 1008 as possible in the light of current activity on silicon bipolar.
- GaAs is not yet a mature technology insofar as high bit rate digital devices are concerned although it shows great promise as a technology which will combine high data rates with relatively low power consumption. It is expected the GaAs field effect transistor (MESFET) devices will enable multiplexing of 140-Mb/s channels into trunks of up to 4 Gb/s. The demand for higher performance systems has led to an increasing level of activity in GaAs research and in the identification of new device structures which show promise of outstanding speed and power performance. It is expected by Project 1008 that GaAs high-speed electron mobility transistor (HEMT) devices may extend the attainable trunk transmission rate to beyond 9 Gb/s. Performance estimates derived by computer modeling of transmission components in GaAs and silicon Subilo N20 were reviewed by Project 1008 for today's technologies and for those in the 1990's. Project 1024 suggested a possible hybrid approach where GaAs provides multiplexing up to 1 Gb/s on the same chip as CMOS handles the lower rate channels.

In all of the above technologies one objective will be to maximize the component densities which the technology can support. The limits are likely to be set by temperature, propagation delays and the problems of interconnects on chip and on the printed circuit boards and backplate. Project 1024 notes that current interconnection technology is likely to be inadequate above 500 Mb/s and that investigations of the newer technologies must include investigation of their interconnection. The possibility of optical interconnects is seen as one of the major long-term options, especially for long links. Wavelength division multiplex is also suggested as a means to reduce the number of high bit rate, long-distance links. Project 2023 concludes that one of the major advantages of ATD is that there is no need for overall synchronization within the switch.

Optical Switching. Optical switches will only be used when they compete on a cost basis with electronic switches having the same features. While optical switching and signaling technologies are still in their infancy, broadband electronic switches are already being planned for all levels of digital cross connects in the networks. However, increasing traffic in the future may require data rates not readily achievable electronically, thus perhaps introducing optical technology. Optical switching techniques which have been considered by various projects involve: lithium niobate, semiconductors (notably GaAs and InP), organic overlap, electro-optic polymers, inorganic overlays, holographic devices, quantum well devices, bistable materials, and electrically activated all-fiber division.

A basic assumption for the IBC Network is that its backbone transmissions will be carried on monomode optical fibers. A further assumption is that optical switches will be required to work with monomode fibers only, although some may be capable of working with multimode.

Project 1019 notes that optical switching should not be considered as a direct, one-for-one replacement for electronic switching. In distributive switching optical switches may be more attractive than in time-multiplexing or demultiplexing applications. An important feature of an optical switch is that the bit rate of the switched channel is scarcely important, and bandwidth is not a limiting factor. Important parameters of an optical switch are its polarization behavior when interfaced to single-mode fibers and the attenuation of the optical path. The latter limits the dimensions of the switch and the fan-out attainable in a distributive switch. No best technology has yet emerged but the characteristics of a few main technologies are likely to suit them to different parts of the overall switching market.

Project 1024 concludes that there is a positive major role for optical switching – but of augmenting rather than replacing electrical switching. Optical switching will be applied where broadband or very high data rate multiplexed traffic is carried.

Project 1019 considers that its major achievement has been to quantify the operating parameters of the main optical switching technologies which it has studied. A list was prepared of performance characteristics which can be used to identify the possible uses of the various optical switching technologies.

Transmission Technologies in the IBC Network

A common assumption for IBC Networks is that optical fiber will be the main transmission medium for the future. It is also assumed that digital signals have to be transmitted and switched. However, the capacity of optical subscriber loops today is quite limited so that, for example, the distribution of TV programs, which is provided easily by analog cable TV systems, can only be performed by means of switching networks within the central office.

Direct detecting optical transmission techniques of today resemble the first generation of radio communications when also direct detecting schemes were also employed. The next generation of radio receivers was of the heterodyne type in use today. A similar evolution towards coherent optical techniques using optical heterodyne receivers is to be expected for optical transmission systems. In direct detection, the digital, completed modulated signal is converted directly by a photo diode to an electrical signal which is amplified and regenerated. The input signal of an optical heterodyne receiver is a modulated optical wave of a determinant carrier frequency, f_c. This wave may be amplitude-phase-, or frequency-modulated. It is fed to a photo diode through a directional coupler together with an optical wave of the frequency f_1 generated by a local laser. The response of the photo diode is an electrical beat frequency signal which corresponds to the frequency difference of the two optical waves. This intermediate frequency signal can be filtered, amplified, demodulated and regenerated by means of well-known electronic methods.

One advantage of coherent optical transmission is that optical heterodyne receivers are, depending on wavelength and modulation scheme, by 10 to 20 dB more sensitive than direct detection receivers. The other main advantage is that any optical carrier of a number of simultaneously transmitted carriers can be transformed to a suitable electrical frequency band. A further important feature of the optical heterodyne receiver is that the local laser can be tuned over a wide frequency range so that each carrier of a multichannel system can be easily accessed.

Project 1032

The main objective of this project was to assess the application of coherent multichannel techniques in IBC network subscriber systems. The following topics were studied: multicarrier frequency stabilization methods, automatic start-up procedures, tuning techniques, intermediate-frequency receiver design, planar optical waveguide structures, wavelength-independent directional couplers, concepts and ideas for integration of optoelectronic components, impact of fiber nonlinearities, integration of services, and evaluation of system concept options.

The 10 specific tasks of this project were:

- The study of services, narrowband and broadband
- Tuning and heterodyning of lasers
- Multitransmitter stabilization
- Start up procedures
- Intermediate-frequency receiver design
- Planar couplers and devices
- Wavelength-independent couplers
- Future integration including polarization control
- Impact of fiber nonlinearities.
- The systems concept study, of which some of the findings were: (1) the initial introduction of coherent multichannel techniques is most likely to be the updating of existing direct detection systems such as narrowband ISDN by supplying many wideband broadcast channels; (2) an alternative approach to a totally broadcast system which uses a mixture of broadcasting and switching is being considered; (3) the coherent system concept has been focused on the search for the most simple solutions for the optical part of the system in order to avoid unnecessary cost; (4) the minimum channel spacing needed to prevent crosstalk between adjacent channels has been calculated; and (5) a suitable concept has been determined for a customer-premises network for coherent multichannel IBC network.

Project 1031

This project investigated the technical alternatives and system performance limits for detection systems. Among the topics addressed were: direct detection systems, heterodyne/coherent systems, multiplexing, and components.

Direct Detection Systems. At present the longest repeater spacings and high bit rate section length products for direct detection systems are being achieved using 1550-nm operation over standard monomode fiber with single-mode lasers. The study includes experimental and theoretical investigation of the special device and circuitry requirements for direct detection systems for operation at bit rates up to 10 Gb/s.

Heterodyne/Coherent Systems. These systems are considered to offer a potential improvement in receiver sensitivity of 10-20 dB or more over direct detection systems at data rates of several Gb/s. Alternative architectures of heterodyne/coherent systems were considered, and the receiver sensitivity was calculated for each configuration.

Homodyne Systems. After assessing the various coherent/heterodyne system options Project 1031 concluded that for long-distance high bit rate applications, homodyne or low-intermediate-frequency heterodyne systems are preferable. Both have the advantage that the bandwidth requirements are much lower than for the high-intermediate-frequency heterodyne technique.

Multiplexing Options. Project 1031 addressed the multiplexing methods that can be used to increase the transmission capacity of a single-mode fiber operating in the special region between 1300 and 1550 nm. The alternatives studied were:

- Wavelength division multiplexing (WDM) with direct detection
- WDM division multiplexing with coherent detection

- Frequency division multiplexing with electrical channel selection
- Frequency division multiplexing with optical channel selection.

The project concluded that with WDM at least eight channels are feasible per fiber window, with negligible effect on system performance due to crosstalk. With 10 Gb/s (using TDM) and up to eight channels (using WDM) the maximum capacity is 80 Gb/s. This might be inadequate should subscriber links require 600-Mbaud capacities.

Component Studies. The project made a detailed study of many of the types of components which are currently available or will be necessary for implementation of advanced optical fiber systems including: stabilized laser sources, optical amplifiers, optical detectors, phase and amplitude modulators, polarization controllers, and passive components.

Project 2036. The project objective was to guide the evolution of INP-based optoelectronic integrated circuits for coherent systems, so that any future R&D efforts are aimed at integrated subsystems which will provide most benefit to system performance or economics and will have widest application. The work of the project was organized under four tasks: integrated sources, optical amplifiers, waveguide and receiver integration, and system requirements.

Project 1029. In this project an up-to-date analysis was made of the state of the art of the technologies required for infrared long-distance communications using low-loss optical fibers. The subjects investigated were: infrared optical fibers, infrared sources, infrared detectors, and system evaluation and comparison.

Technologies in the Customer Access Network

These technologies are covered in the projects discussed herein. It was thought from early studies in Project 2031 that the initial subscriber network would use a time division multiplex/wavelength division multiplex (TDM/WDM) mix. The number of fibers per subscriber and the tradeoff from mixing WDM and TDM have now been further analyzed.

Network Configuration

A hexagonal model was developed for the distribution network – i.e. the area covered by a distribution center with connections to dispatching and branching boxes and ultimately the subscriber. This model has enabled the developers to make valid cost comparisons.

These studies suggest that the best initial approach for the subscriber network would be to use a single fiber per subscriber with a combination of two-wavelength WDM and TDM on a single-mode fiber cable network. Shared fiber may reduce cost but would lose flexibility. However, this needs further investigation.

A number of system configurations for the optical subscriber loop were considered by Project 1015. The evaluations were based on use of single-mode fiber and light emitting diode (LED) sources, and made a number of other assumptions. The only feasible options appeared to be: two fibers per subscriber – one for each direction, or one fiber per subscriber – separating upstream and downstream directions by WDM techniques. End-to-end losses of the first option were estimated at 8 dB over 3 km and around 10 dB for the second option.

Project 1025 gave preference for a dedicated customer link with a light source at each end. Preferred wavelength windows are 1300 μm for downstream and 1500 μm for upstream. Models of the customer access connection considered by the project included symmetrical 150 Mb/s transmissions and asymmetrical 600/150-Mb/s systems.

Project 1023 compared the advantages and disadvantages of networks – local, centralized, and dispersed with star, bus, and ring configurations using asynchronous time division (ATD). A common functional model was devised. Preliminary conclusions are that the best individual subscriber loop is star configured. If remote units are used these can be connected to the local exchange by star or ring configurations.

Microelectronic Components

A review of system requirements by Project 1025 identified the system bit rate as the most significant aspect affecting the design of the electronic area. Two maximum data rates were proposed: 150 Mb/s and 600 Mb/s.

Power dissipation is an important consideration. To reduce costs, a high degree of integration is needed, with a large number of gates in each package. A technology is needed with low power consumption to ensure that the total power dissipated conforms with the limits set by the systems teams.

The possible technologies identified by Project 1025 are:

- Si-bipolar: ECL, EECL, CML
- CMOS (medium speed, high complexity, low power)
- NMOS (similar to CMOS but with disadvantages)
- BiCMOS (little present advantage)
- GaAs (very high speed, less mature technology). Project 2001

This project examined many scenarios which may be able to satisfy the subscriber premises network requirements and concluded that:

- the SB (subscriber) interface should be electrical.
- A dual network solution may be more suitable than a single one.

- An active star is the best topology for a high-rate network.
- Optical fiber is to be preferred at very high bit rates; coaxial cable and fiber optics can be used at lower rates.
- RF cordless will not be suitable for high bit rates but will be useful at low bit rates.
- Some form of bus is the best topology for a low-rate network.

Sources

Source studies in Project 1015 were confined to LED's. The surface emitter configuration option was eliminated early due to poor coupling efficiency into single-mode fiber. Two other types, the edge emitter (ELED) and the superradiant emitter (SRLED), were found to have comparable performances. The team assessed how, under typical operating conditions, pulse broadening limits the maximum bit rate times transmission distance, output power, and receiver sensitivity. The following possibilities for single fiber/two-wavelength operation were found:

1) 150 Mb/s downstream
   34 Mb/s upstream .... OK for 10 km
2) 300 Mb/s downstream
   150 Mb/s upstream .... OK for 3 km
3) 600 Mb/s downstream
   150 Mb/s upstream .... marginally OK for 3 km

A market survey of LED's showed nine companies offering 1300-nm ELED's, three offering 1550-nm ELED's, and five offering 1300-nm SRLED's. Five companies announced low-cost lasers in 1986 operating at 1300-nm and offering an order of magnitude increase in power over ELED's.

Project 1025 considered the following possibilities for sources:

- Planar electroluminescent diode
- Edge emitting electroluminescent diode
- Superluminescent diode
- Laser in multilongitudinal mode operation
- Single-frequency laser.

On the basis of systems requirements assessed by Project 1025 (maximum bit rate 600 Mb/s; maximum length 10 km; wavelength in range 1300-1550 nm), a laser with direct modulation is the recommended option.

For sources Project 2001 concluded that based on drive and reliability LED's offer the best solution short-term, but in the long term, laser diodes will be more competitive. They will then be more suitable for subscriber premises networks.

Detectors

The output power of an ELED is quoted as -25 dB mean at 60°C. The total path loss, depending on the bit rate, fiber type, and fiber wavelength is quoted as 13-15 dB for 3 km, and 17-20.5 dB for 10 km. The fiber loss contribution is, however, only around a third of the total path loss.

The limit of receiver sensitivity for today's mass production receivers is about -38 to -40 dBm at 140 Mb/s. The following system calculations in Project 1015 indicate the required receiver sensitivity for the two-wavelength scheme using standard single-mode fiber:

3 km at 1.3 μm
  for ELED at 150-300 Mb/s ....-39 to -40 dBm
  for SRLED at 150-300 Mb/s ...-35 dBm
10 km at 1.3 μm
  for ELED at 150 Mb/s ....-46 dBm
  for SRLED at 150 Mb/s ....-41 dBm
3 km at 1.55 μm
  for ELED at 34 Mb/s ....-43 dBm
  for SRLED at 34 Mb/s ....-38 dBm

In P/InGaAs- and HGCdTe-PIN detectors have been identified as the preferred detectors.

Integrated Optoelectronic Devices

Monolithic integration of a detector and an amplifier was considered by Project 1015 to be promising with respect to receiver sensitivity and cost reduction. LED sources and integrated PIN-FET receivers are expected as the natural evolutionary path to achieve the cheapest source/detector combination that satisfies the local transmission and processing criteria, according to Project 1013.

The detectors required for the subscriber loop are expected to need to go to 280 or 560 Mb/s. The sensitivity required is typically 40 dBm for 140 Mb/s at 1.3 μm, with an ELED emitter. This is achievable today using discrete HgCdTe diodes.

The project is concerned with establishing the feasibility of producing integrated detector amplifiers for the 1.3- to 1.5-μm band because these are expected to lead to cheaper components in larger numbers than today's hybrids. The technical work involves growing the appropriate HgCdTe on GaAs, and investigating the protection of critical parts of each material from the other and from temperature effects. Aspects of the work include:

- Investigation of MCT PIN diodes including grown resistance ohmic contacts
- Examination of MCT growth onto GaAs substrates using both pure wafers and specially prepared partially processed GaAs wafers, including investigation of any effects of chemical cross contamination

- Investigation of GaAs devices incorporating protected MCT segments formed in mid-process
- Formation of MCT diodes in material grown on GaAs and from the above
- Design of a proposed prototype integrated structure
- Consolidation of economic benefits.

The first three of the above have been successfully carried out and shown relevance of the technology to frequencies above 1 GHz. Also a nonoptimized but promising MCT diode has been made with a GaAs substrate. The optimization of a diode formation into holes in GaAs and a demonstration of optimized MCT diodes on GaAs containing MESFET are proposed for the RACE main program.

The main components considered by Project 1025 for optoelectronic integration are:

- 1300-nm laser with monitor detector
- Integrated circuit driver for laser
- 1550-nm laser with monitor detector
- PIN photo diode
- Receiver amplifier
- 1300/1550-nm WDM component (fiber or micro-optics).

Other studies undertaken in technologies in the customer access network which will not be discussed in detail here are:

- Reference components
- Standardization
- Subassemblies
- Packaging
- Economic chip manufacture
- Broadband optical components
- Wavelength-selective components
- Optical fiber interconnection
- Cables and fibers
- Optical budgets
- Installation
- Cordless subscriber premises network
- Other media networks.

Terminal and Display Technologies

This section deals with the technologies required to implement the terminal equipment 1 (TE1 in Figure 1) functional grouping of the Subscriber Premises Reference Model between the S interface and the human or machine user interfaces (See Figure 1). Technologies which are most closely associated with the implementation of the S interface will also be candidates for the implementation of the TA (terminal adapter) functional grouping at the S interface. Because of the expected extensive use of the IBC terminals, chosen implementation technologies must be reliable, low-power, and cheap.

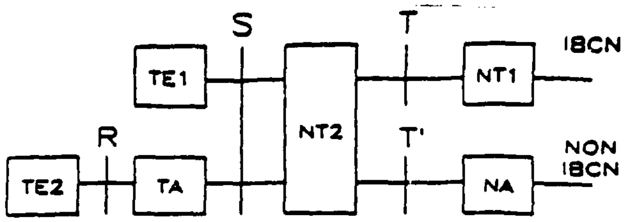

Figure 1. The Subscriber Premises Reference Model.

Project 2003 surveyed and evaluated the technologies and applications of large-area flat-panel displays to identify areas of future development work for support in RACE main projects. Europe now consumes 10 percent of the flat-panel displays manufactured worldwide but manufactures only 0.1 percent of the world total. Therefore, whenever possible, proposed projects will have demonstrator panels as project deliverables.

A 5-year program will fall short of the ultimate high-definition television (HDTV) requirements, particularly for panel size. It is proposed that an evolutionary approach be pursued for 18 months, when a major review is performed on the three technology candidates to determine which technology can best achieve the HDTV objective.

Development of the different flat-panel displays required by IBC terminal products must be guided by the consumer's requirements for terminal function. Flat panels offer new user interaction possibilities, and will require an IBC terminal demonstrator to emphasize and evaluate these concepts. Ongoing European Strategic Program Information Technologies (ESPRIT) projects cover some of the aspects discussed here. Project 2003 suggests a coordination between RACE and ESPRIT.

It is probable that in the future displays will become an increasingly integrated part of a system, rather than being sold as a component. Thus, display development must be actively pursued in Europe to support systems. Also, the performance of a system will, to a great extent, be judged by the appearance of the display.

At present no flat-panel display can match the performance of the conventional shadow mask CRT. It is unlikely that the demands of HDTV will be met by the flat-panel displays before the year 2000. The three technologies for flat-panel display are liquid crystal, electroluminescent, and plasma. Liquid crystal displays have the advantage of low power, low cost, and readability in sunlight. The dominant liquid crystal display technology (600x128 pixels) is the twisted nematic effect, which limits displays to 128 rows because of problems with contrast viewing angle. The next generation of alphagraphic, monochrome liquid crystal displays will be based on the supertwist birefringence effect, which has a higher contrast ratio and a wider viewing angle. Displays of 200 rows (600x200 pixels) – i.e., 25 lines of text, and possibly 50 lines of text – may be produced. However, such displays in monochrome will not match video frame rate requirements.

Effort in liquid crystal displays is now being directed toward active matrix addressing, regarded as the ultimate solution to the fabrication of complex liquid crystal displays. Full-color active matrix LCD's with a 20-cm diagonal and operating at video frame rates have been demonstrated. Most effort is concentrated on thin-film transistors employing mainly amorphous silicon. Two ESPRIT projects are studying active matrix addressing.

The main disadvantage of the active matrix approach is that it is difficult to make large increases in the area of the display, due to the use of expensive equipment and yield loss due to the increase in the number of active elements. An alternative approach to the fabrication of a complex LCD is the use of ferroelectric LCD's, which exhibit very fast switching speeds (100 μs) and memory, offering the potential of displays with 500-1000 rows operating at a video frame rate. Fast switching and memory have been demonstrated, but color and greyscale must be added.

Electroluminescent displays can now commercially provide high resolution (3 pixels/mm) as monochrome alphagraphic displays with complexity up to 512x640 pixels using ac thin-film technology. Page A4-size panels have been constructed in laboratories. The advantages are: good contrast, video speed, wide viewing angle, high resolution, and ability to be highly multiplexed. The main problems to be overcome are: low brightness, the provision of color and greyscales, and reduction in power consumption. However, the feasibility of red, green, and blue electroluminescent phosphors has been demonstrated and the vertical stacking of the color pixels may eventually provide very high resolution displays. Provision of greyscales has also been recently demonstrated.

Plasma panel technology has proven to be suitable for large screens, an example being a 60x80 cm (1 meter diagonal) panel with over 2 million pixels, developed in the US by photonics. Thomson of France has recently demonstrated a panel of 1024x1024 pixels with an active useful area of 307x307 mm. Until now the products are monochrome, with speeds suitable for video. Problems relate to high cost, high power consumption, and the provision of color and greyscales.

Because of integration and cost considerations, display driver integrated circuits are generally considered as an integral part of the flat-panel display module. For active matrix LCD displays amorphous polycadmium selenide and polysilicon thin-film transistors are available for the integration of driver circuits directly on the glass panel, although improvement in transistor characteristics will be required. For LCD driving, state-of-the-art silicon CMOS integrated circuits operating at 5 volts meet the speed requirements of video frame rates. Technology modifications are necessary to achieve 20- to 25-volt outputs for active matrix and ferroelectric LCD applications. Symmetry of the CMOS output buffer is ideal for providing no net dc component for LCD driving.

At present, integrated circuit drivers with 64 outputs (no greyscale) and 16 outputs (with greyscale) are available, but the disadvantage of the high voltage and current requirements is the high cost of the integrated circuits, which often constitute 50 percent of display panel costs. Although consuming slightly higher power than electroluminescent displays, plasma displays operate at a lower voltage, typically 90 V, such that symmetrical push-pull drive can be used on both rows and columns.

The development of a mass production process from a RACE R&D demonstrator is one of the major exercises required to put a flat-panel display into the market, and for some devices complete automatic fabrication may be the only viable method to obtain acceptable yields. At present there is no European knowledge base related to the mass production of flat-panel displays and little appreciation of the interaction between R&D processes and mass production yield. This know-how must be built up within Europe or bought from the outside. If the expertise is to be developed within Europe, then there is the need to set up programs to achieve this, with the development of automated equipment as one of the main objectives.

Five related flat-panel display tasks have been identified as potentially suitable for inclusion in the RACE main program. Two are based on LCD's, another on ACTFEL (an emissive technology with excellent contrast and viewing angle), and a fourth on system architecture. These four tasks would take 5 years to produce an approximately 50-cm diagonal demonstrator. The fifth task is to produce a much larger HDTV feasibility demonstrator using the best flat-panel display option identified.

If Europe is to maintain control of the mass production of flat-panel displays, then attention must be given to suitable programs for developing equipment for its mass production. The development of 50-cm diagonal display in active matrix or ACTFEL will need a team of 100 over a 2-year period at a cost of 20 million ECU. The capital production plant would cost 200 million ECU, with a 200 million ECU running cost.

The cost of developing large displays of about 1.5-m diagonal is difficult to predict because the production processes have not yet been devised. If we assume that the cost per unit area of displays are broadly similar to those for current flat-panel display technologies and that the cost of production increases in proportion to the display area, then the production cost for a 1.5-m diagonal display will be about 10 times more than for a 50-cm display. To a first approximation, the cost of a plant to make

1 million 1.5-m displays will be about the same as that to produce 10 million 50-cm displays.

Based on reasonable assumptions the cost of developing a production line for 50-cm displays at a throughput of 10 million parts per annum is about 300 million ECU. Equipment for fabricating 1.5-m diagonal displays at 500,000 units per year will cost about 10 million ECU. The cost to develop such equipment for integration into an automatic production line with a throughput of 1 million parts per annum could be about five times the above cost or 50 million ECU. Since six units could be required for a large-scale production line, the equipment development cost could be as much as 300 million ECU.

Coding Projects

A major feature of line and frame synchronized transmission of TV images is its high level of information redundancy, particularly when there is little or no change in the scene being transmitted. This redundancy provides an opportunity in digital transmission systems for reduction in the bit rates required for transmission of TV pictures. The reduction of bit rates for transmission and the subsequent reconstitution of the received data to provide a TV image of acceptable quality are the functions of complementary coders and decoders, or codecs.

Historically, codecs have been developed on an individual basis to meet specific applications and to match specific transmission rate standards, for instance, video telephony on a 64 kb/s ISDN channel or for compression of digital TV from the studio standard of 216 Mb/s to a 140 Mb/s transmission standard. Codecs are also employed for the compression of speech or music.

The following projects address the subject of coding and codecs:

- Project 1007 – integrated video codec
- Project 1017 – low bit rate codec in IBC terminal equipment
- Project 2000 – low rate imagery network elements
- Project 2023 – variable bit rate video coding for ATD
- Project 3001/2/3 – coding case studies
- Project 3009/10/11/12 – coding performance objectives.

Whereas bit rate reduction seems likely to be useful to reduce the current 216 Mb/s to as low as 34 Mb/s, there still remain some difficult problems to be overcome. The effective practical compression ratio here is about 5:1, and a similar reduction ratio for HDTV would result in a bit rate of about 240 Mb/s with perhaps greater difficulty in view of the initial higher quality and the greater viewer expectation engendered by the prospect of large, bright, high-resolution displays.

Comments

Although the RACE program is getting started a year later than planned, the excellent investigation during the feasibility study conducted in 1986 provides a plan of action supported by well-established facts about the current state of the art and reasoned conjectures about what might be achieved over a 5-year period.

All aspects of the telecommunications problem in an integrated broadband network are included in the investigation now getting underway. The funding and manpower commitment appears to be sufficient for achieving substantial results, even though the undertaking is a mammoth one.

The technical talent exists is Europe to achieve the goal. The problem is to bring the talent to bear on the problem in sufficient concentrations to get results. This is made more difficult due to the wide distribution of the talented people over so many different countries.

Another major challenge is to get the financial and technical resources together in a few companies to produce the sophisticated products that will be required. This can succeed only if the effort is concentrated in a few (three or four) European companies so that the expected revenue will be sufficient to justify the enormous development costs.

Reference

RACE: Consolidated Preliminary Report of the RDP projects, Commission of the European Communities, Directorate General XIII, Telecommunications, Information Industry and Innovation, June 1987.