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Cover:
A module for a high-performance RISC processor subsystem developed and manufactured by Ericsson using available technologies for ASIC packages, substrates and assembly

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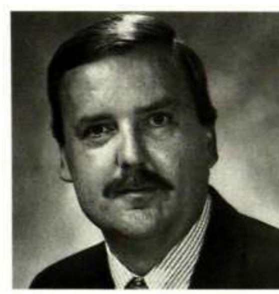
Ericsson Review bids new publisher and editor welcome

In January, 1995, Håkan Jansson succeeded Anders Igel as publisher of Ericsson Review. At the same time Håkan Jansson was appointed Senior Vice President of Technology of Telefonaktiebolaget L M Ericsson.

Håkan Jansson



Steve Banner

Steve Banner has been appointed as the new editor of Ericsson Review. Steve Banner commenced his employment with Ericsson in Montreal, Canada, in 1990, after 16 years' employment in various technical capacities with Telecom Australia. His initial responsibility to establish a training organisation for Ericsson's mobile data product, Mobitex, was later modified to include AXE training for the rapidly-expanding CMS88 Design and Technical Support organisations in Montreal. In 1993, he transferred to Florida in the United States, carrying out a technical support role for Ericsson's regional mobile telephone customers. In addition to his technical background, Steve is a qualified adult educator with a Diploma of Teaching, Bachelor of Education, Graduate Diploma of Education and an almost-completed Master of Educational Administration to his name.

Per-Olof Thyselius has retired as editor of Ericsson Review, after four decades in Ericsson's service. During his three years as editor , he has edited well over fifty articles describing products, systems and services at the leading edge of telecommunications technology. The wide scope of subjects dealt with truly reflects Ericsson's imposingly broad-based operations. During Per-Olof Thyselius's editorship, the Spanish edition of Ericsson Review was resumed. His experience from many parts of Ericsson and his extensive network of personal contacts have been of great value to the in-flow of articles for Ericsson Review. He has also been instrumental in streamlining the editorial work.

A Swedish Airborne Early Warning System Based on the Ericsson ERIEYE Radar

Sten Ahlbom, Paul Andersson and Rolf Lagerlöf

Ericsson Microwave Systems AB is introducing an Airborne Early Warning system on the international market. The radar can be installed on aircraft of different types and sizes according to the demands of the application and the customer's preferences.
The Swedish Armed Forces have placed an order for six Ericsson AEW systems. In this case, the radar will be installed on the Saab 340 aircraft. The authors describe the Swedish system solution – based on a fixed phase-array antenna carried by a small turbo-prop aircraft – and the performance of the ERIEYE radar, which compares favourably with that of larger and more expensive AEW systems.

The Swedish Armed Forces have placed an order for six Airborne Early Warning (AEW) systems. The first of them will be delivered early in 1996.

The radar of the early warning system is being produced by Ericsson Microwave Systems AB. It will be installed on the Saab 340, which is manufactured and marketed by Saab Military Aircraft in Sweden. Saab is also responsible for the modifications necessary for the aircraft to carry the equipment – modifications that involve power supply and cooling as well. The aircraft is small compared with those used in other AEW systems.

The complete airborne system is designated FSR 890 in the Swedish Air Force.

Fig. 1
The ERIEYE radar carried by a SAAB 340. The aircraft is only slightly modified in the tail-unit to compensate for the aerodynamical influence of the dorsal unit

Ericsson Microwave Systems AB is introducing the AEW system on the international market under the name ERIEYE Mission System. The radar will be installed on a suitable aircraft together with command and control systems and additional avionics, as required. Aircraft of different types and sizes can be chosen according to the demands of the application and the customer's preferences.

The system is well suited for both civil and military service.

A key element of the Swedish AEW system is the fixed, phased-array antenna of the radar which makes it possible to use a small aircraft. The design and system trade-offs made in order to achieve an optimal system solution are discussed in the following.

Why AEW?
Ever since the air war in Vietnam, AEW systems have played a key role in all major air operations. The Gulf War made the AWACS's characteristic mushroom on top of the aircraft's fuselage well-known over the world through TV news reports from the war scene. AWACS stands for Airborne Warning and Control System.

What AEW represents today was born, one might say, at the American attack against Okinawa during World War II. Destroyers of the U.S. Navy were deployed at some distance from the island to be able to detect and warn against Japanese counter-attacks by air. Many ships were attacked by Japanese suicide pilots, who approached from a low height above the sea.

Due to the curvature of the earth's surface, aircraft flying at an altitude below

Fig. 2
ERIEYE on Fairchild, Metro III

Box A

Main antenna specification:

Frequency band	S-band
Antenna aperture	8 x 0.6 m
Polarisation	Horizontal
Scan sector, azimuth	360°, optimised for 150° on either side of the aircraft
Beam positions, elevation	0° in transmitting mode -2.5°, 0°, 2.5° in receiving mode
Lobe width, azimuth	0.7°
Lobe width, elevation	9°
Gain	36.5 dBi
Side-lobe levels	Well below isotropic

200 metres cannot be detected by a ship's radar until the range becomes shorter than about 5 kilometres.

Today's superfast aircraft have reduced the time for warning; still longer warning ranges are required, both over the sea and over land. An AEW system that cruises at a height of 10,000 meters "sees" the horizon at a distance of about 400 kilometres. This gives not only an overview of a complicated air scenario but also detailed information, such as the speed and course of all flying vehicles detected in the vast air space around the aircraft.

Well-known AEW Systems

One basically rather old AEW design – operational since 1960 – is the well-known American Hawkeye dedicated for radar surveillance over the open sea. At the very start, the aircraft used was designed to carry its radar with an antenna that rotates together with the radome – the rotodome. The rotodome also has aerodynamical properties that add to the lift of the wings. Hawkeye is designed to be based on an aircraft carrier.

Hawkeye, which is operative in several countries, will be updated with a fifth generation of the radar. Variants of the radar electronics have been installed on other types of aircraft.

AWACS – E-3 Sentry (operative since 1977) has been updated and modified several times. Plans to extend its lifetime and improve performance with new computers and new avionics are being discussed.

AWACS has a Russian – formerly Soviet – counterpart (passing under its American name Mainstay A-50) installed in an Ilyushin IL-76. Its exterior is similar to that of AWACS.

All the AEW systems mentioned have a rotodome of about the same diameter that gives them a very characteristic appearance.

Studies have shown that the optimum frequency for this type of equipment is found in the L-band (1-2 GHz). For long-range performance of the radar system it is essential that the antenna aperture be maximised. However, to meet the lobe width requirements in azimuth, an L-band antenna would have to be in the order of 15 metres. Such a large antenna cannot be carried by a small aircraft; it would be difficult even for a large one. A sound compromise is S-band (2-4 GHz) and an aperture of about 8 metres, which is found on AWACS and Mainstay and on FSR 890.

A SWEDISH SOLUTION

From the outset, the Swedish Armed Forces were intent on acquiring an AEW system that was well adapted to Swedish conditions. Good radar performance over the open sea and over land was a necessity; yet the costs of the system and of keeping it operative should only be a fraction of those of existing systems. Eventually, some crucial techniques that evolved in a positive way enabled a solution with a fixed phased-array antenna on a small turbo-prop aircraft. The development of a concept adapted to the Swedish require-

Fig. 3
The drawings of the AWACS and of the ERIEYE aircraft are in the same scale. Note that the diameter of the large aircraft's rotodome and the length of ERIEYE's dorsal unit are of about the same dimension. The sensitivity of the radar is directly proportional to the square of the antenna aperture area. This explains why the range performance of ERIEYE compares favourably with that of AWACS in spite of the smaller aircraft

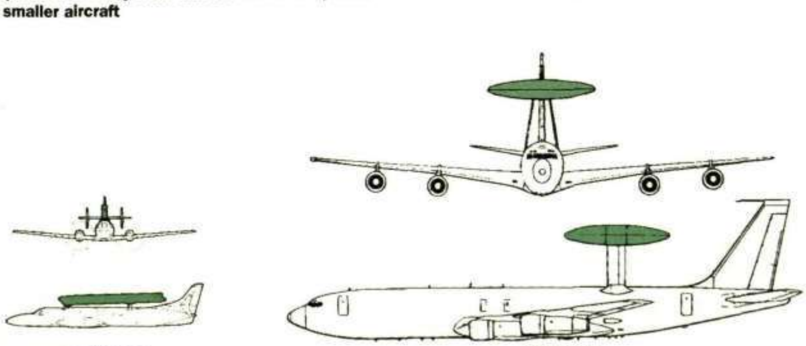


Fig. 4
ERIEYE on Fokker 50 (Fokker KingBird)

ments could finally be initiated. An important circumstance was the size of the aircraft, which significantly affects the AEW system's life-cycle cost in several ways.

All over the world, turbo-props are used for passenger flights on regional routes. They are cost-effective, they fly with a small crew and have very moderate demands on airfields and maintenance capacity. In addition, their speed range is well suited to the radar.

FSR 890 will be able to perform its surveillance tasks in peacetime as well as in a defence situation when a well-planned military attack is launched by a qualified aggressor. It will be a flexible, highly mobile component in the complete surveillance system, which is characterised by its long detection and tracking range even in the case of low-flying targets.

In Sweden, the air command and control organisation is located in well-protected ground-based centres. A two-way data link between FSR 890 and the ground organisation reduces the need for operators on board the aircraft. A small crew is one of the prerequisites for the small-aircraft concept; another is the choice of a fixed radar antenna.

The officers in the command and control centres will be responsible for the control of radar functions and for the command of the air defence forces. They will be able to base their decisions on continuously updated radar track presentations from FSR 890 and on radar data from ground-based systems in the area of ongoing operations. With the Swedish solution, those in the command and control centres will have the best overview of the air situation. They will be able to make strategic decisions on how to use the AEW system efficiently as an integral part of the complete surveillance equipment.

The development of a Swedish AEW system has necessitated far-reaching optimisation efforts at different levels of system design. The level of automation of radar functions and of the integrated avionics has to be high, since the size of the aircraft leaves no room for technical operators to control these functions. Automation also means that the ground operators can concentrate on their tactical tasks instead of being called upon to supervise or correct different functions in the aircraft.

In the following, the focus of this article is on the phased-array antenna. Several factors that had to be taken into consideration when acquiring the low side-lobe levels are also discussed, as is the way in which full advantage has been taken of the electronic scanning of the antenna beam. The result is advanced radar energy management that adapts to changing requirements for detection and tracking performance.

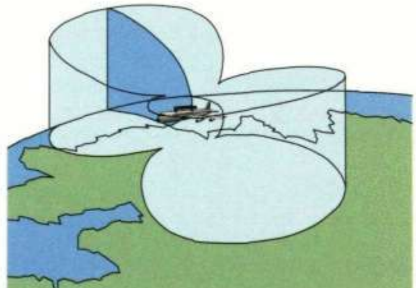
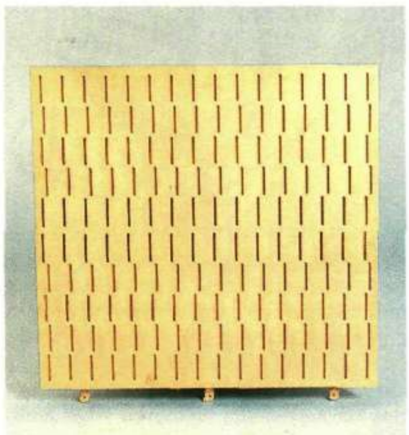


Fig. 5
The total coverage of the scanning antenna lobe using antenna apertures on both the port and starboard sides is indicated. A radar operating high above the earth's surface "sees" the horizon at a much longer distance than a ground-based radar. An AEW system that cruises at an altitude of 10,000 metres has an overview of a vast air space and a markedly improved capability for detecting even low-flying targets at a great distance

THE ACTIVE PHASED-ARRAY ANTENNA

A fixed antenna of phased-array type can be designed to give little drag and only minor effects on an aircraft's aerodynamics in other aspects, too. Through small

Fig. 6
Front view of the antenna plate with sixteen waveguides, each with ten slots



modifications of the tail-unit, these effects can be compensated so that an acceptably low level can be obtained even on a small aircraft.

A distributed antenna system
The antenna consists of two equal apertures positioned back to back in the dorsal unit facing the port and starboard directions. Together they provide a total scanning sector of 360° with optimum performance within a sector of 150° on each side of the aircraft.

The antenna is located on top of the aircraft in such a way that its performance is not affected by reflections from the fuselage or the rotating propeller blades.

Distributed transmitter/receiver modules (TRMs) in solid-state technology are used, one for each of two radiating waveguides placed directly opposite each other on the port and starboard sides of the dorsal unit. Fast microwave switches are used to connect either aperture of the radar system to the TRMs.

Considerable efforts have been made to reduce the weight of the antenna. The TRMs are ram air-cooled, which results in lower weight load than with a liquid cooling system. The latter, on the other hand, would provide better means for accurate temperature control of the TRMs. This is not critical in the present solution, however, thanks to an efficient on-line calibration system.

The distributed phased-array antenna offers several very interesting future opportunities to generate complex antenna lobe patterns. With many simultaneous lobes, a number of tasks can be be processed individually or in combination.

A distributed antenna undergoes graceful degradation when failures occur in the transmitter/receiver modules, whereas a central transmitter loses its function completely when the transmitter tube fails.

Antenna aperture
Each of the two antenna apertures consists of 12 plates with 16 vertically oriented waveguides that form a continuous plane on either side of the dorsal unit. With this orientation, the antenna lobes are horizontally polarised. The aperture surface must be mechanically stable under flight conditions and designed and mounted so that the deviation from an ideal plane surface will nowhere exceed half a millimetre.

Each of the 12 plates is manufactured by milling the 16 waveguides out of an aluminium block. An aluminium sheet metal with slots is dip-brazed onto the block to close the waveguides. All superfluous metal in the block is milled off to reduce the weight as much as possible.

The waveguide slots are of the shunt type, offset from the centre line of the broad wall of the waveguides. Single-ridged waveguides have been chosen to make the broad dimension narrow enough to allow for large scanning angles without generating any grating lobes.

In the electrical design of the antenna, each individual slot length and the slot displacement from the centre line are calculated. The mutual coupling to all other slots of the aperture has to be taken into account in the process. To achieve this, a number of programming tools for synthesis and analysis were developed. With a slot model, the slot admittance in the waveguide can be calculated as a function of the slot length and the displacement, also including the effects of the mutual couplings. A combination of theory and measurements was used to design this model.

Extensive computer simulations were made in order to derive acceptable tolerances that could be maintained even when a large number of antenna apertures were produced without individual trimming.

Box B

Cross-section of the dorsal unit

The dorsal unit consists of a box-like structure in lightweight, composite materials - mainly carbon fibre reinforced epoxy. Either long side of the box serves both as a radome - with radar transparent fibres - and as a structural element with great stiffness and strength.

In the middle of the box, an H-shaped structure holds the 192 transmitter/receiver modules made of a precision-cast aluminium alloy. Each module is cooled from channels underneath and above. The antenna elements are placed between the H-structure and the radomes on both sides of the dorsal unit. Each of the eight-metre long antenna apertures consists of twelve panels with sixteen thin-walled antenna waveguides, made of aluminium.

The aerodynamically shaped struts are long enough to reduce reflections from wings and propellers. The six struts are also arranged in such a way that the dorsal unit is isolated from torsional strain from the fuselage.

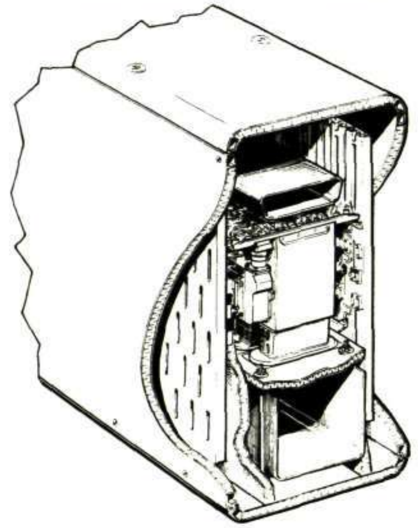


Fig. B
Cross-section of the dorsal unit

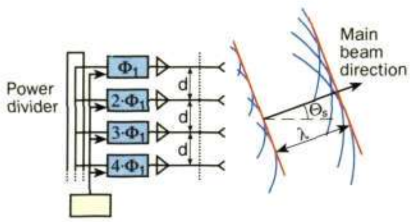


Fig. 7
Elementary waves combine into a resulting wavefront. Relation between phase increment and scan angle:

$$\Phi_1 = -2\pi \frac{d}{\lambda} \sin \Theta_s$$

- Phase shifters
- Antenna elements
- Computer
- TRM
- Spherical wavefronts from each element
- Resulting plane wavefront

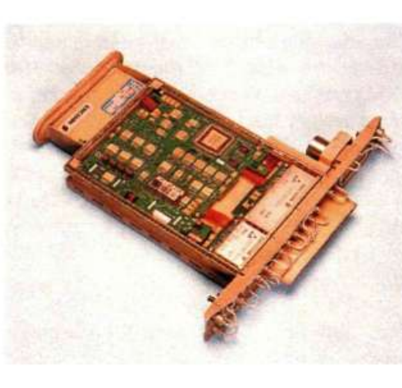


Fig. 8
A TRM seen from the digital electronics side

However, the strict specification of sidelobe levels places stringent demands on manufacturing skills and machines.

Each waveguide is divided into two electrically separated parts, each with five slots. This design is used to introduce a limited scanning function in elevation.

The waveguide feeders are mounted at the rear of the antenna plate. They are made in stripline technique with a Σ- and a Δ-channel from the two electrically separated parts of the waveguide.

Radome
The radome must be transparent to the radar signals for the whole frequency band and for all scanning angles. To keep the weight down, the radome must also contribute to the stiffness of the dorsal unit. This is essential for the required tolerances of the aperture plane to be maintained.

The radome – a sandwich construction of two thin skins of Kevlar fabric in an epoxy matrix and with a Nomex honeycomb spacer between the skins – is removable. Each radome is made in one piece, about 8.3 x 0.7 m in size. The overall thickness is about 25 mm.

Transmitter/receiver module
The transmitter/receiver modules – TRM – are manufactured by Ericsson Microwave Systems in Mölndal. The design includes high-efficiency output power transistor amplifiers and highly integrated microwave circuits and digital electronics.

The technology trends in these areas will lead to even greater efficiency, higher integration and even more reduced size and weight. This will benefit future upgrading of the radar, resulting in improved radar performance and reduced total weight.

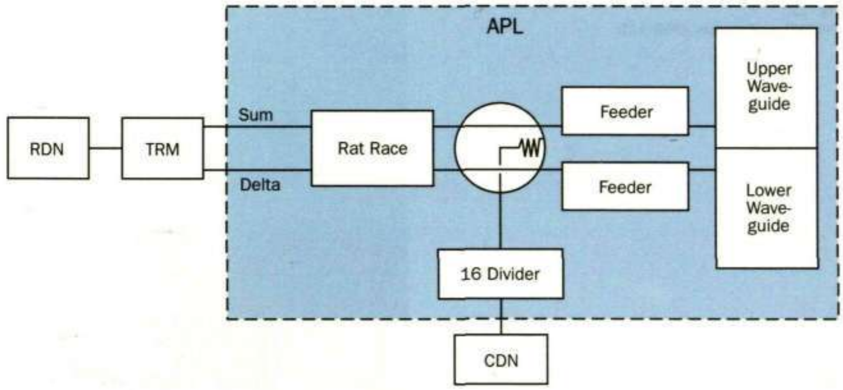
Radar distribution network
The TRMs are connected to the exciter/receiver in the aircraft by a radar frequency distribution network. A radar signal is generated in the high-frequency generator and – by means of several dividers/combiners – distributed with equal amplitude and phase to each of the 192 TRM inputs. Stripline technique is used in all dividers; their circuits being etched on copper-clad teflon laminates. The dividers are connected to semi-rigid coaxial cables.

Calibration distribution network
The system also includes a separate calibration network. This network is of the same type as the radar distribution network but larger (384-divider), since it distributes the calibration signal to all Σ-signals in the waveguide feeders via a -30 dB hybrid. The last 16-divider is mechanically fixed directly to the back of the antenna plate.

Cables, dividers etc. must be carefully selected, since the temperature of passive components in the dorsal unit will adapt to the outer air temperature. For this reason, the coaxial cables are designed with dielectrics with a low temperature coefficient. Any temperature gradient over the length of the dorsal unit must have minimal influence on the signal phase.

Phase and amplitude calibration and control
As has been mentioned already, an important characteristic of the antenna in an airborne radar with high sensitivity is the level of the sidelobes compared with that of the main lobe.

Fig. 9
Block diagram of one of the sixteen waveguides in an antenna plate (APL). The waveguide is divided into an upper and a lower part, which are fed into a "Rat Race" that separates the Sum (Σ) and Delta (Δ) signals. From the calibration distribution network (CDN), a reference signal is loosely coupled to the Sum signal through one of the 16 output ports of the "16-divider" attached to the APL. The Sum and Delta signals from each waveguide are coupled to a TRM (transmitter receiver module), which in turn is connected to all other TRMs in the radar distribution network (RDN)



Side lobes must be so low that unwanted ground and sea clutter can be efficiently suppressed. Low side lobes are also required in order to suppress signals from other emitters in the neighbourhood and signals from active hostile jamming. The low side-lobe level specification necessitates tight control of the amplitude and phase of each TRM. When transmitting, the amplitudes of all TRMs have identical settings, whereas an amplitude taper is applied in receive mode. The phase and amplitude control must cope with the large temperature variations that are typical of an air-cooled system.

In a complex system with many components, accurate control of all signals becomes difficult. In a distributed system, the transmitters and receivers account for a majority of the errors that are introduced. Careful design of these parts with respect to long-term stability of performance, supply voltages, internal heating and ambient temperature is necessary but not sufficient. Measures must be taken to compensate for any residual phase and amplitude errors.

Fortunately, the phase in transmit mode and the phase and amplitude in receive mode can be accurately controlled through a compensating technique based on comparisons between reference calibration values and actual values.

The reference calibration of each produced antenna is made in a measuring room covered with non-reflecting material. This near-field measuring facility has the

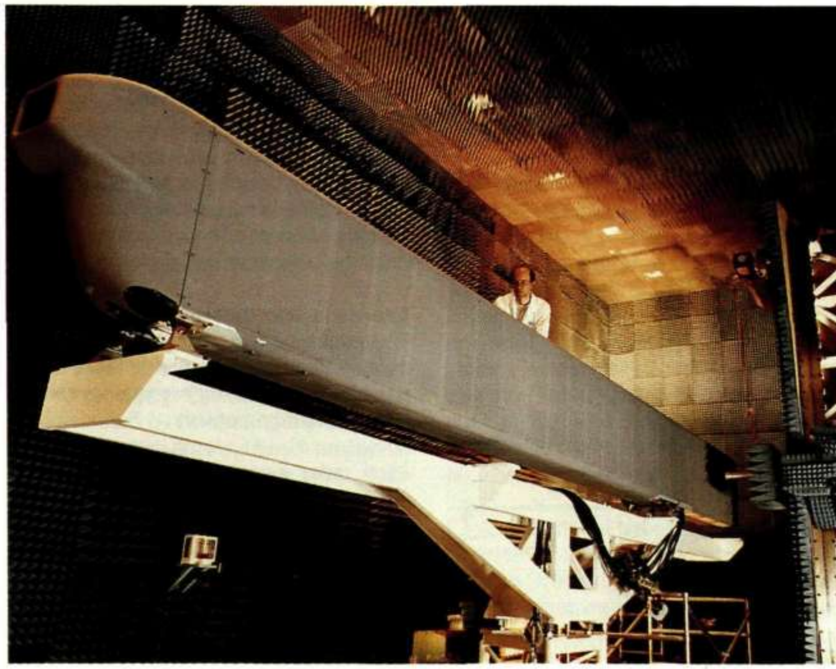


Fig. 10
The dorsal unit in the near-field test facility

Fig. 11
ERIEYE on Embraer EMB 120

required high accuracy and well-controlled temperature conditions to make measurements reproducible.

Reference calibration involves iterative computer runs of programs performing the two transformations nearfield-to-farfield and farfield-to-slot Excitations. The initial table is a Taylor-type of tapering with sufficient low side-lobe level. If the far field does not fulfil the side-lobe criteria, a transformation to the excitations shows how to correct the tapering. A new iteration can then be performed.

The table of calibration data includes amplitude and phase of the outputs for each frequency and each lobe position for both the starboard and port apertures in both transmit and receive node. The values are referenced to the output signals from the reference calibration network.

Internal calibration system
The only part of the calibration system that cannot be controlled under flight conditions is the passive high-frequency calibration distribution network.

Each radar signal path is corrected as soon as the comparison between the reference calibration values and actual values indicates a deviation exceeding a preset value. The time interval between calibrations can also be chosen, depending on the surveillance situation in which the radar operates.

One TRM channel at a time is calibrated, while the other channels are shut off. These calibrations should be of short duration and made at lengthy intervals. Otherwise, temperature changes might disturb the calibration process.

ELECTRONIC SCANNING OF THE ANTENNA BEAM

The main radar task
The main task of the ERIEYE radar is to survey a vast air space and a large ground area by detecting targets and tracking these targets. The characteristics of a surveillance scenario can range from no targets at all to a very complex situation with many manoeuvring targets.

Target data is continuously transferred to a command and control centre, where it is used to complete and maintain the picture of the air space, and to guide the operators' decisions on operational measures. The accuracy – and reliability – of target data is crucial.

Guiding own aircraft to identify or intercept other aircraft (visual or radar contact) is an action that requires high-accuracy target data.

Building up knowledge of a hostile target from different independent sources is an activity for which high reliability of the identity of the tracked target is vitally important.

Fig. 12
Example of search and track beam pattern with agile antenna beam operation enabled by the electronically steered antenna (ESA)

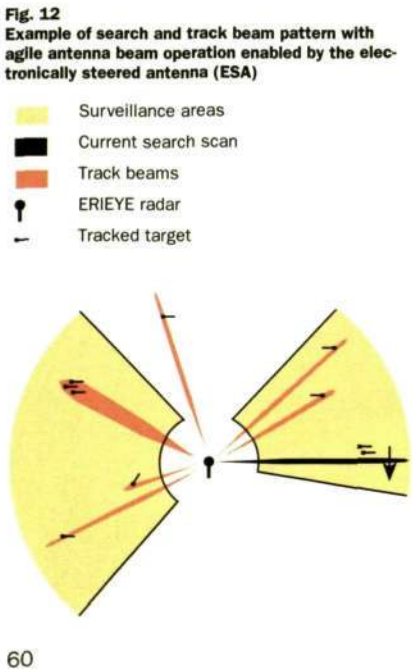
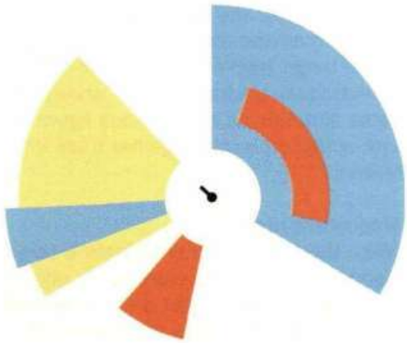


Fig. 13
Example of surveillance area configuration with different operational tasks

Sea target surveillance
Air target early warning
Air target high-performance tracking
ERIEYE radar



Target tracking

The objective of target tracking is to extract the most probable target trajectories, given a series of radar detections as input. Varying target detection probability, varying target manoeuvres and varying target density must be considered, as well as the probability of false detections caused by ground clutter or internal system noise. The risk of intentional radar jamming must also be considered.

Radar track performance falls into the following five categories:

Track initiation range
The distance from the radar where a stable track can be started.

Track accuracy
The difference between the track and the target's true position, speed and course.

Tracking probability
The ability to maintain tracking.

Tracking continuity
The ability to retain track identities in situations involving interference with other targets.

Target manoeuvre response
The ability to follow a target manoeuvre.

Three main parameters determine the achievable radar performance level in these categories:

- Measurement accuracy
- Illumination energy
- Measurement rate

High measurement accuracy, high illumination energy and high measurement rate give high tracking performance.

Measurement accuracy

The measurement accuracy is normally determined by the antenna beam width. An improved target position estimate can be calculated by comparing the detected amplitude in two antenna beam positions, separated in azimuth.

Illumination energy and measurement rate

Illumination energy is given by illumination power and the dwell time of the target. The maximum illumination power, which depends on the high-power transmitter technique, the power-generation technique and the maximum allowed weight, can be considered fixed for each radar system.

In conventional radar system concepts, with a rotating antenna, measurement rate and dwell time (and thus the illumination energy) are interdependent parameters because of the mechanical construction. Long dwell time gives a low measurement rate and a high measurement rate gives short dwell time. Furthermore, time-consuming scanning in not desirable directions is unavoidable.

The consequence, for a conventional radar system, is that a general trade-off has to be made between measurement rate and the illumination energy of a target.

In modern concepts, with electronically steered antennas, dwell time and measurement rate can be controlled individually. The radar energy can be concentrated in directions of interest. A slow scan with high illumination energy can be used for early detection of new targets. For each tracked target, an individual measurement rate and an individual dwell time can be chosen by means of situation-adapted track beams, in order to fulfil specified tracking performance requirements.

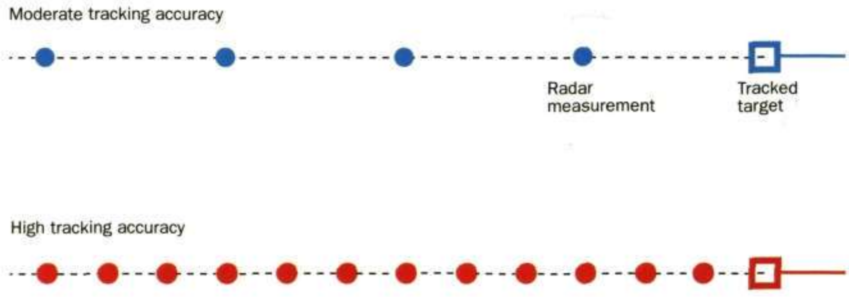
This leads to the key solution that opens for great improvements of tracking performance: dynamically adapted measurement rate and illumination energy, enabled by an electronically steered antenna.

ERIEYE surveillance operation

The ERIEYE concept provides operational freedom. The surveillance configuration is based on operator-defined surveillance areas. These can be ground-fixed or aircraft-fixed, and two or more areas can be operating simultaneously. The operator selects an operational task for each surveillance area, and a set of selectable operational tasks can also be pre-defined, tailored to the customer's operational requirements.

Each operational task has a unique combination of tracking-performance characteristics: track initiation range, track accuracy, manoeuvre response, active target interference protection in dense situations, etc.

Fig. 14
A high measurement rate is automatically adapted to the tracking-accuracy requirements (which may differ for different operational tasks)



An Early Warning task is a typical example. In this case, a long track-initiation range is required, whereas the requirements for other characteristics are moderate.

A high-performance tracking task is another example. In this case, the requirements for accuracy, manoeuvre response and target interference protection are of greater importance.

Other operational tasks are sea target surveillance, helicopter surveillance, ground moving target surveillance, etc.

Combinations of surveillance areas with different operational tasks, fully or partly overlappping, can be used to achieve a more complex surveillance configuration.

Individual targets can also be assigned high-priority status. In this case, tracking performance will be maximised, and these targets will be tracked even outside surveillance areas.

The measurement rate of a tracked target is dynamically and automatically adapted to the current situation, based on the requirements of the chosen operational task or on a high-priority status, if any. The measurement rate is automatically affected, as shown in the examples below, due to the different requirements in the following typical situations:

Track initiation
When a new target is detected, a special track-beam sequence is performed in order to find out whether it is a real target and, if so, to establish stable tracking.

Track accuracy requirements
The measurement rate is adapted to the current target behaviour. The target tracker filter (Kalman filter) continuously monitors the uncertainty of target data, due to measurement and prediction errors. The uncertainty increases as a function of the time elapsed from the last measurement. The point in time when the level reaches a maximum allowed level, corresponding to the stipulated requirements, will set the measurement rate. This means that moderate track-accuracy requirements automatically give a low measurement rate and vice versa.

Tracking probability
If a measurement fails due to loss of target detection, new track beams will immediately be created and the measurement will be repeated. Different strategies are used for this rescue sequence, depending on the situation.

Tracking continuity
In target interference situations, a low updating rate leads to an increased risk of miscorrelation. Figure 15 shows an example.

The measurement rate will be changed adaptively according to the situation, in order to keep the uncertainty areas of tracks small and thus increase the ability of the target tracker to retain the identity of individual tracks. Fig. 16 shows the same situation as the previous figure but with active protection against track interference.

Manoeuvre response
When the target tracker detects a target manoeuvre, the measurement rate is increased in order to get a fast response and to be able to follow the manoeuvre.

Fig. 15
In traditional radar systems, the algorithms of the target tracker must solve all target data conflicts. The figure shows the result of a correlation failure in a conflict situation

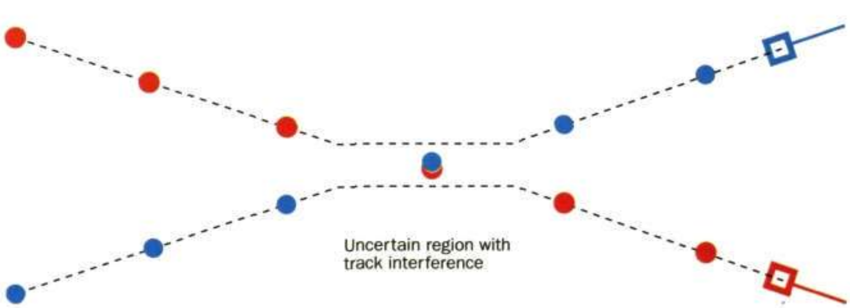
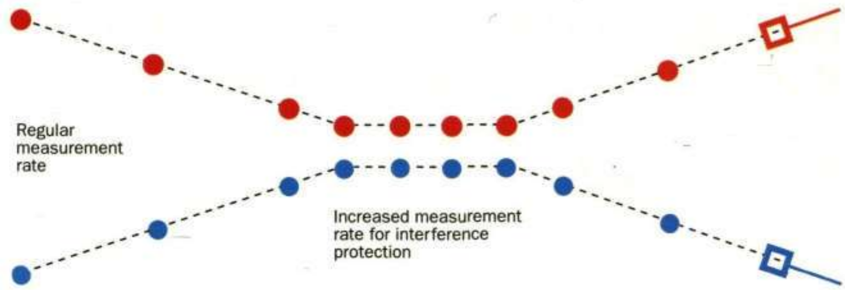


Fig. 16
Active protection against target interference considerably decreases the probability of miscorrelation



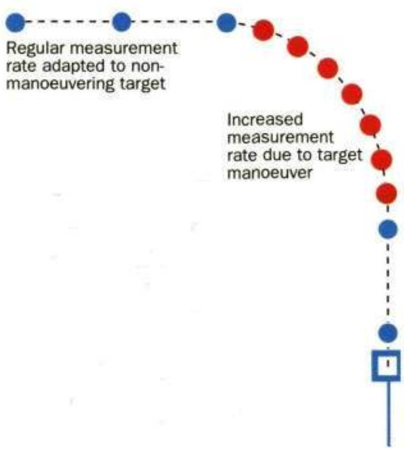


Fig. 17
The measurement rate is dynamically adapted to target manoeuvres

An energy management system is used to control the balance of radar energy used for searching and the energy used for track beams, and to coordinate overlapping surveillance areas efficiently. The main tasks are to direct the surplus of energy in directions of great importance at low surveillance workload, and to take the appropriate measures according to certain strategies to adapt to an increasingly high surveillance workload, if needed.

The technique enables close interaction between co-operating subsystems on board the aircraft, such as IFF (Identify Friend or Foe), SSR (Secondary Surveillance Radar), ESM (Electronic Support Measures) and the Command & Control System. Special additional track beams for different purposes can easily be interleaved in the regular radar scanning programme, if requested. This can be made in order to verify detections from other subsystems.

CONCLUSIONS

The Swedish AEW system is characterised by good radar performance over land and over the sea. The concept is based on a fixed phased-array antenna on top of a small turbo-prop aircraft, and this solution significantly affects the system's life-cycle cost. A number of factors – the small and relatively inexpensive aircraft, the high level of automation of radar functions and integrated avionics, the small crew, and moderate demands on airfields and maintenance – contribute to improved cost-effectiveness.

The algorithms, used to control the electronic beam steering, adapt radar energy management to the tactical situation and to target priorities – depending on threat levels, manoeuvring, and the number of targets – in a way that cannot be matched by a radar system with a rotating antenna.

Ericsson's AEW system that is now being introduced on the international market, under the name of ERIEYE Mission System, is well suited both to civil and military service. Turbo-props (the type of aircraft employed in the Swedish solution) are used for passenger flights on regional routes all over the world.

High-performance Packaging for a RISC Processor Application

Monica Bakszt and Eva Hellgren

Central processors for telecommunication switching systems are very complex, with high clock speed. System design must rely heavily on advanced packaging technology for the best possible system performance to be achieved.
The authors describe the development of a packaging concept for a high-performance RISC processor subsystem. The project started in December 1990 and was finished in February 1994.

SYSTEM REQUIREMENTS

In the early 90's, Ericsson Telecom was running a three-year project to develop a packaging concept for a high-performance RISC* processor subsystem. The RISC module developed in the project was designed in two versions – in the following called demonstrator module and final product. The reason why the module comes in two versions is twofold: the redundancy concept at system level was changed in the course of the project, and so were the packages provided by the IC supplier.

The RISC module – the core of a central processor unit – operates at very high data speed. RISC-architecture processors (in this case Motorola 88110) are used; they are surrounded by large gate arrays with up to eighty simultaneously switching output (SSO) signals. The clock frequency on the substrate is 50 MHz.

High-performance packaging was used in order to minimise crosstalk and ground bounce. The characteristic impedance on the substrate had to be approximately 75 ohms. The physical volume of the RISC-module packaging was a critical factor, since the space was very limited at the mother-board level.

The power dissipation for the RISC processors was estimated to about 8-10 W/chip, which meant that managing the heat dissipation from the packages posed a major problem. To achieve the lowest possible delay on the module, it was necessary to keep the components close together – at the cost of high-density power dissipation. The overall power dissipation was estimated to 25 W/dm^2. For each IC, the module must be able to cope with 6 W/cm^2. Forced air cooling was allowed, since the equipment is planned for use in a central office environment. Normal air speed in this type of environment is 0.6 m/s, and one temperature cycle of 15°C is expected per day.

* RISC, Reduced Instruction Set Computer

CHOICE OF TECHNOLOGIES

Different packaging concepts were evaluated. The most promising concept was to use a multichip module (MCM) technology, Box A; a technology evaluated in earlier prestudies at Ericsson Telecom.[1] These studies showed that better signal transmission characteristics, lower power dissipation, lower electromagnetic radiation and smaller size can be achieved by using multichip modules instead of single-chip packages.

In 1990, a RISC processor test vehicle was designed at Ericsson Telecom.[2] Of

Box A

MCM Technologies

MCM – Multi Chip Modules
MCM denotes a number of technologies that may be used to achieve high packaging density on the substrate. The substrate consists of a base, dielectrics and conductive layers. Different combinations of base, dielectric and conductive material give different properties. Ceramic, silicon, PCBs, metal, AlN or SiC are examples of base materials. The conductors can be copper, aluminium or thick-film conductors. The dielectric can be of SiO_2, epoxy, polyimide or benzocyclobutane (BCB) or BT-resin. The chip may be mounted on the substrate by different methods: wire bonding, TAB (tape automated bonding) or flip chip. MCM technologies have been classified by their base substrate:

MCM-L
Resin laminate substrate with multilayers of electrical interconnects. Low unit cost and a large number of vendors are the key to the proliferation of this type of MCM for moderately complex functions.

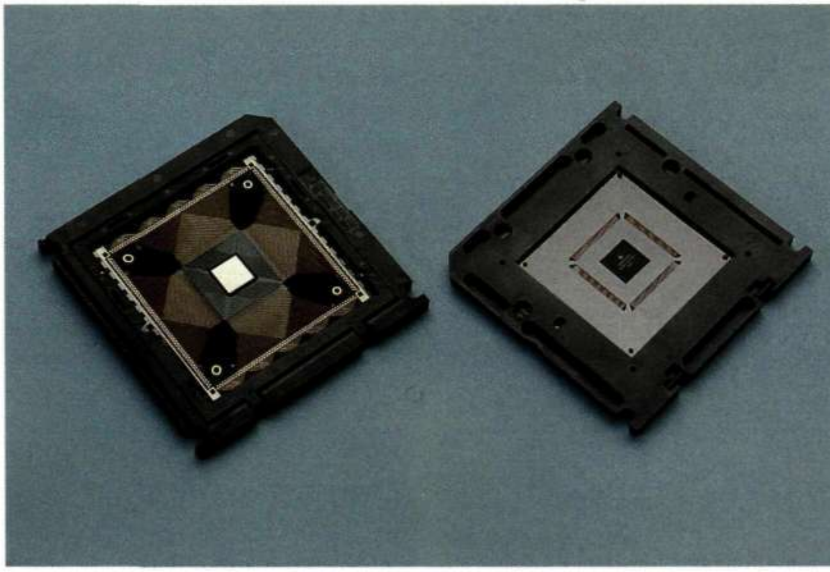
MCM-C
Ceramic substrate with multilayers of electrical interconnects. Fine interconnect line capability results in high-density packages for very complex applications.

MCM-D
Thin-film deposited silicon substrate with multilayers of electrical interconnects. Ultrafine interconnects for minimal size in high-performance applications.

These technologies may also be mixed. MCM-D/C is an MCM with ceramic base. Power and ground usually with ceramic thick-film technology and with pad layers in thin-film technology to achieve high density.

KGD
The known-good-die concept is the ability to produce bare dice that have been tested/burned-in to guarantee good integrated circuits for applications such as MCM. In such applications, standard probe testing is not sufficient. Standard tests cannot verify satisfactory AC or DC performance.

Fig. 1
TAB tape. Both sides of the tape are shown



Box B

Components

BGA – Ball Grid Array Package
Ball grid array packages are surface-mountable packages with an array of solder balls at the bottom of them. There are hermetic BGAs, which use a ceramic substrate, and non-hermetic BGAs with a laminate substrate. The packages used for the RISC module consist of a high-density ceramic single-chip BGA package, with the chip attached in a flip chip manner. The chip can also be connected with wire bonding inside the package. The package has solder balls made of high-temperature solder (90% lead and 10% tin) for connection to the printed circuit board. The balls are soldered to the bottom of the package with an eutectic solder (37% lead and 63% tin). The package, 25x25 mm in size, has 361 solder balls with a 1.27 mm pitch. See Fig. 13.

TAB – Tape Automated Bonding
TAB tape is a package with the chip connected directly to an etched metal lead pattern on a polyimide film (tape). The pattern is designed to enable test of the chip before the TAB components are assembled. See Fig. 1.

A TAB component is mounted in the following way: the chip and part of the tape with the metal lead pattern are punched out, and the leads are formed with a special tool. The TAB component is placed on a circuit board with tin-lead-plated solder pads; a thermode (hot bar) is used to press down the leads and solder them to the board.

Connector sockets and pins
A solderless interconnection system consisting of compliant sockets with round pins. The nickel-gold-plated sockets are pressed down into holes in both the MCM and the mother board, and the metal body cuts into the hole wall to form a gas-proof connection.

Connector sockets on the module and on the mother board are aligned by means of guide and distance pins. The connector pins are then inserted through the two sockets. The pins, which can be of various lengths, have a diameter of 0.3 mm. See Figs. 4 and 5.

The set-up is disconnected by pulling out the pins one by one.

the three MCM technologies that were then evaluated, MCM-D technology gave the best results – but also represented the highest cost.

To gain optimum benefit from MCM, the whole processor system has to be designed with this technology. Decisions on which ASIC packaging technology to use must be made early in the design process, parallel with ASIC design. ASIC inputs and outputs must be matched to the substrate materials and the bonding technology chosen.

Although MCM technology was available when the project started, there was a serious lack of "infrastructure" (in terms of routines and processes) both in-house and outside Ericsson. Long-term cooperation between users and IC-suppliers was necessary, and fully tested bare dice – what is called Known Good Die (KGD) – must also be available.

Two types of MCM technology – MCM-L and MCM-D – were considered for the project; its purpose being to achieve optimum high-density packaging. To be able to deliver the demonstrator in time, standard technologies had to be used, both for ASIC packages, assembly and substrates. A safe solution was to use in-house substrate material (standard glass epoxy laminate), MCM-L technology, and packages provided by the IC-supplier.

MODULE DESIGN

Two important factors had to be taken into account in the choice of design:

- The area available on the mother board was limited and it was necessary to keep all the memory units on this board close to the processor module.
- Packages that were to be supplied by the ASIC supplier had to be used, namely TAB (Tape Automated Bonding) packages, Box B.

Demonstrator module

The demonstrator module was to be used by the system designers for evaluation of performance and logic functions. The module consisted of five chips: two RISC processors and three large gate arrays, 123K gates, H4C CMOS process, from Motorola. The pin count was estimated to 300 – 450 on each chip. At the time the module was designed, Ericsson Telecom was evaluating the TAB technology, planning a basic release of this technology. However, using a pin count exceeding 300 in the first application was considered too risky, and one of the gate arrays was therefore divided into two chips. This resulted in four gate arrays, each with 296 pins, including power and ground. Standard TAB tapes were used as packages. The processors were mounted in TAB packages with 306 pins each.

The Motorola dice had I/O pads prepared for TAB mounting. This means that the I/O pitch was 0,10 mm, which was finer than what could be achieved with wire bonding.

As has been mentioned already, the project had to rely on packages available from the IC supplier. The 88 110 RISC chip was intended for high-volume computer customers who use low-cost substrate materials, e.g. standard PCB epoxy laminates. To be able to use TAB tapes on these materials, a large fan-out of the tape leads was necessary (resulting in a larger pitch on the board). The outer lead pitch was therefore 0.3 mm for the ASICs and 0.4 mm for the processors. This large fan-out required long tape leads.

Table 1

Simulated transmission properties of TAB tapes

Noise Level	**CMOS 1500 ps**		
	Tape 1 *36 mm body size, one-layer tape*	*Tape 2* *24 mm body size, two-layer tape*	*Tape 3* *24 mm body size, one-layer tape*
20%	Terminated 1/5	–	Unterminated 3/5
10%	Terminated 2/5	–	–
5%	Terminated 3/5	Terminated 1/5	Terminated 2/5

1/5	GND	ACT	ACT	QUIET	ACT	ACT		
2/5	GND	ACT	ACT	QUIET	ACT	ACT	GND	
3/5	GND	ACT	ACT	QUIET	GND	ACT	ACT	GND

The body size for the processor TAB was 36 mm. There was some doubt whether the performance of the packages would meet the specified requirements and be good enough for the system it was to support. The coupled inductance of TAB leads generates noise spikes on quiet outputs and in ground connections on chips. Crosstalk was a potential problem; it was impossible to predict how the tape would perform at 50 MHz.

There was no practical experience of CMOS 50 MHz systems at the time – only experience of H-spice simulations. If sufficient power and an adequate number of ground connections were used, the system would operate satisfactorily, but since the tape had a limited number of pins available for power and ground, the number of these pins had to be optimised.

Replacement of the large tapes by tapes with shorter leads was considered. It would give better performance, a finer pitch and a smaller body size. TAB tapes with a fine pitch can be used as long as the outer lead pitch is at least 0.2 mm. Ericsson Telecom has capacity for in-house production of very high density PCBs, but the production technology at that time set the lower line/space limit to 0.2 mm.

Higher performance can also be achieved with another type of TAB tape – a tape with two metal layers, the second one serving as a ground plane.

Evaluation of TAB designs

An evaluation program for simulation and measurement was carried through in cooperation with Motorola.

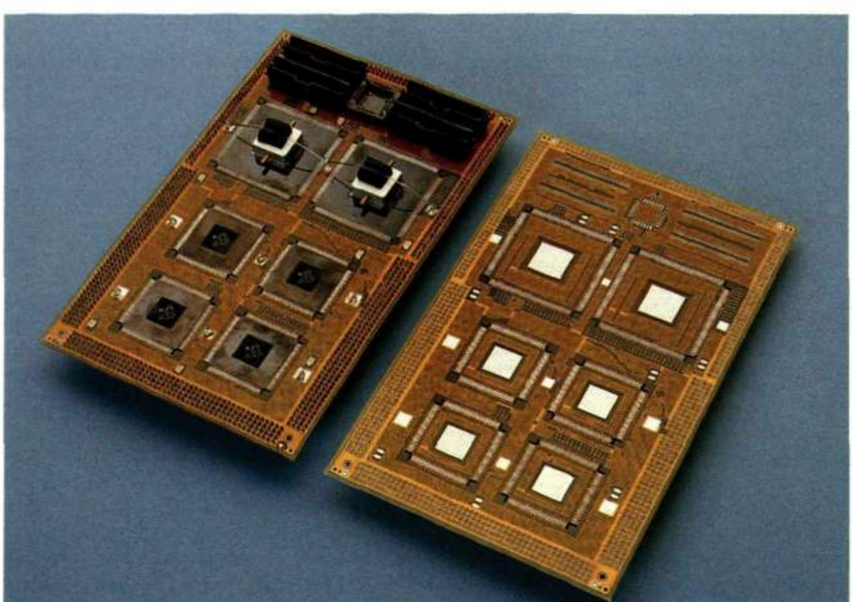
Three TAB tapes were evaluated, one with 36 mm and two with 24 mm body size. One of the 24 mm tapes was a two-metal-layer tape. Simulations and tests were performed by both Motorola and Ericsson. Motorola provided SSO test chips, tapes and SPICE models; Ericsson provided the test boards. The two-layer tape was a Motorola patent-pending design.

In the project, measurements on the SSO test chips focused on the module's high-current, low-output drivers. The ringing/resonance on module nets, power and ground noise and crosstalk were also measured. The measurements showed that two-layer TAB tape reduced the noise on quiet outputs to approximately 2/3, compared with one-layer TAB tape. The two-layer tape did not improve ringing characteristics.

In the simulations made by Ericsson, the TAB lead arrays were modelled with the Greenfield 2D field solver. Near-end and far-end crosstalk, as well as ground bounce, as a function of the ground pin/signal pin ratio, were logged by means of the Phyllis SPICE simulator. The effect of series termination of signals was also taken into account.

The results of the simulations can be summarised as follows: terminated signals

Fig. 2
Printed circuit board (right) and assembled board (left) that were used for the demonstrator module. The board size was 90x150 mm



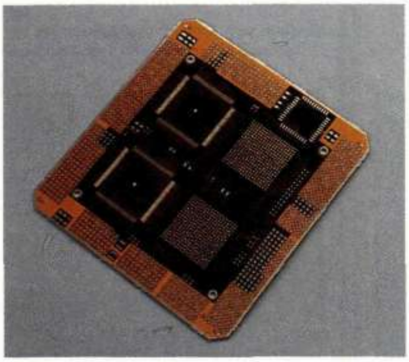


Fig. 3
Printed circuit board for the final product; board size 107x115 mm

reduced the noise, and the larger the number of ground connections, the lower the noise. To reach the lowest level – in this case 5% – the TAB tapes in all the different simulations except one had to have terminated signals. The largest tape, with 0.4 mm outer lead pitch and 36 mm body size, had to have terminated signals and three ground connections on every fifth signal to reduce ringing and reach the accepted noise level, Table 1. The result was logical, but it was nevertheless difficult to determine whether the simulations were accurate or not. In a real application, some signals (asynchronous signals, for example) are more sensitive to noise than others.

It was decided that another ASIC tape should be used: one with 24 instead of 28 mm body size. But since Motorola had other customers who wanted to retain the large 36 mm tape for the processor, and since it was difficult to prove that it would not work, this tape was not replaced. Instead, a large number (300) of terminating resistors were used. Very small ones (0.5 x 1 mm) were chosen, to minimise the space occupied by resistors.

Logic tests on the module showed that the packaging concept worked, even though full speed could not be reached. This was not necessary for the logic verifications, however.

Final product

In the second, final version, the module consisted of eight chips: six 123K-gate H4C gate arrays and two RISC processors. The RISC processors were delivered in a new package; Motorola had changed the processor package to a ceramic Ball Grid Array, BGA. The BGA was IBM's Surface Mount Array (SMA) package, which provides 361 pins with a 50 mil pitch (1.27 mm) on a 25 mm carrier.

In this case, the module had to operate at 50 MHz. One advantage of the BGA packages was that their electrical performance was much better than that of the large (36 mm) body size tape. The two BGA packages, together with two ASICs (gate arrays), were assembled on the primary side of the board. The four remaining ASICs were mounted exactly opposite to them, on the secondary side. This mode of mounting minimised the distance between the processors and the ASICs, which reduced the weight of the most critical factor in the application: the signal delay on the board and in tape leads. The configuration also made terminating resistors unnecessary. The signal quality was improved, and 1 ns was gained on critical nets.

Laminate substrate

Laminate substrates (printed circuit boards) were used for both the demonstrator module and the final product. The laminate substrates – manufactured at Ericsson Telecom – were basically improvements of the standard printed circuit board (PCB) technology. A standard glass epoxy laminate (FR-4) was used. The boards were built up of eight layers; six of them were signal planes, one plane was for power and one was used as a ground plane. The total thickness of the finished printed circuit board was approximately 1.2 mm.

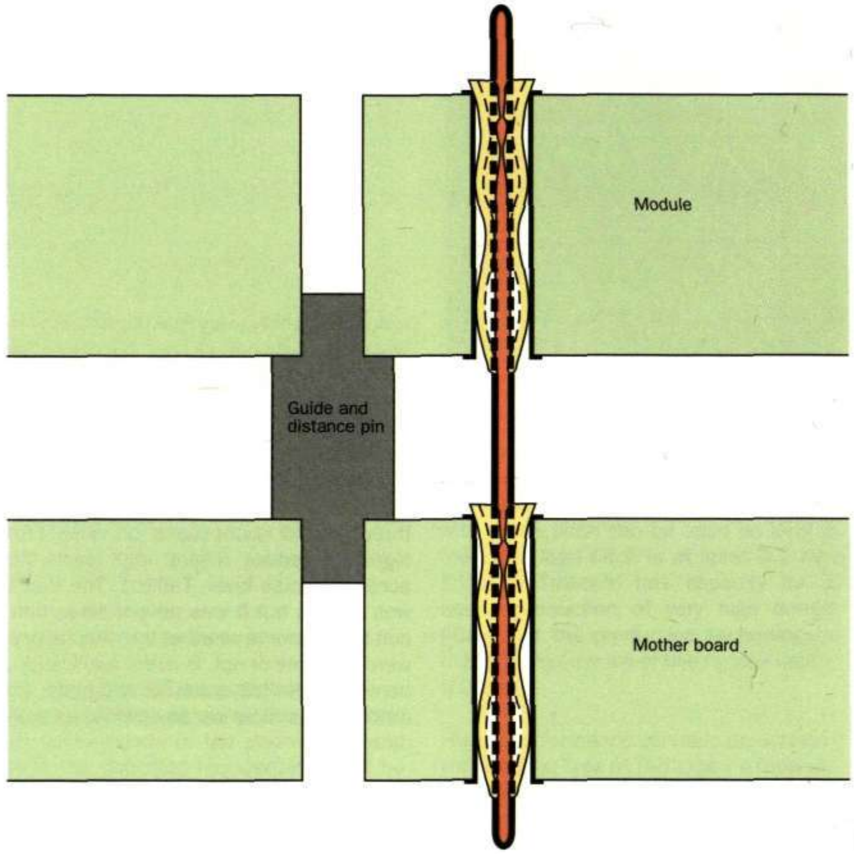
As regards the conductive pattern on the boards, the same design rules applied to the demonstrator module and the final product. They were stretched towards the dense side and set by the footprint of the BGA packages used. The conductors were 0.1 mm wide, with 0.2 mm spacing between them. The total length of the conductors on the final product was 45.5 m.

The number of holes on the demonstrator module and on the final product was approximately the same. The final product had 1855 drilled holes; the majority of them were through-plated via holes with a diameter of 0.2 mm. The holes for connectors, sockets and pins, totalled 870 and had a diameter of 0.55 mm, Figs. 2 and 3.

Due to the single-sided assembly on the demonstrator module, this board had to be larger (90x150 mm). The final product, which had double-sided assembly, was reduced to a board size of 107x115 mm with a total pin density of 19.8 pins/cm^2.

Initially, the high packing density posed some difficulties when bare boards were to be tested: a standard PCB test with a regular pin fixture was impracticable. Other methods had to be looked for and, finally, a double-sided "flying probe" tester was chosen. This is a fixtureless machine that can be equipped with various types of probes and used for tests of substrates

Fig. 4
Connector sockets and pin inserted through a module and a mother board



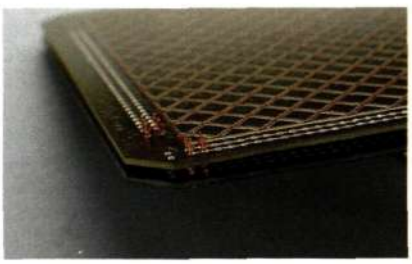


Fig. 5
Two boards aligned parallelly to show connector sockets and pins

for multichip modules and boards with very high packing density.

ASSEMBLED MODULE

Demonstrator module

The demonstrator module was built up of only six chips – all of them on TAB tapes – in a single-sided assembly on the substrate. The 300 terminating resistors were placed wherever space allowed, and the connectors – shown on the board to the left in Fig. 2 – were placed along the edges.

Final product

The final product was assembled with six 296-pin ASICs, all on TAB tapes, two RISC processors in BGA packages, 50 passive chip components and 870 connector sockets/pins, Figs. 4 and 5. Two ASICs and the processors are placed on the top side, with the remaining four ASICs exactly opposite on the underside of the board, Fig. 6. Both sides of the board are shown in Fig. 7.

The production of the modules is described in Box C.

THERMAL MANAGEMENT

Demonstrator module

Since the demonstrator module was only used for test runs in the laboratory, water cooling was used to absorb and dissipate the heat generated during the tests. This is shown on the board to the left in Fig. 2.

Final product

The total power dissipation from the module is approximately 30 W; each of the

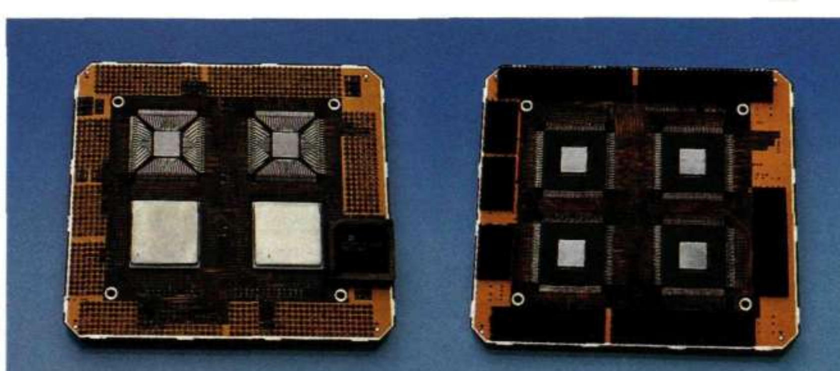


Fig. 6
The top side of the final product assembled with two Ball Grid Array packages and two TAB tapes (left). To the right the underside of the final product assembled with four TAB tapes

Fig. 7
The assembled final product. The underside with four TAB tapes can be seen in a mirror

Box C

Production of Module

ASSEMBLY
Assembly of the module is difficult because of the mix of technologies used. The assembly operation starts with a tested laminate substrate and tested components. The primary side of the board is screen-printed with solder paste, and all surface mounted-devices, BGA packages and passive chip components are assembled. Reflow soldering in a convection oven with nitrogen atmosphere is used. A Boundary Scan test is made as a preventive measure, to avoid repair due to misplacement of the BGA packages on a fully assembled module.

The connector sockets are inserted, and the TAB components are assembled and soldered with a hot bar on the primary and secondary side of the board. A second Boundary Scan test is then made to verify the connections of the TAB tapes.

The heat sink is assembled on the primary side of the module. The mother board and the module are aligned, and connector pins are inserted into the sockets on the module and through to the mother board. Finally, the secondary heat sink is attached by means of screws. See Fig. 12.

microprocessors dissipating 8-10 W. The TAB-mounted gate arrays and the board must have the same temperature, 80°C, since the Kapton film expands more than the board when the temperature rises. The air inside the module is stationary, which means that heat must be removed.

The anodised aluminium heat sink is designed to perform several functions: to manage the heat generated by the chips and components, to serve as a shield for electromagnetic radiation and to support and hold the module in place on the mother board, Fig. 8.

Fig. 8
The final product with heat sink. The underside can be seen in a mirror

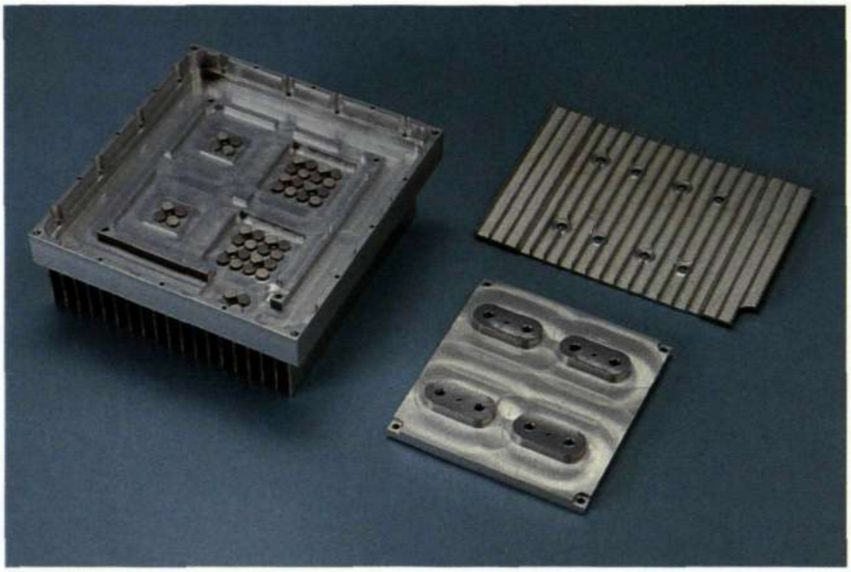


Fig. 9
The various parts of the heat sink

The heat sink consists of several parts: a finned case for the top side of the assembly, a thinner part with short fins for the underside, and pistons with helical springs that bear against the heat-dissipating surface of each chip and component. There is one block of four pistons for every TAB tape and a group of four blocks of four pistons on each BGA package, Fig. 9. To improve heat transfer, a thin layer of grease was applied between the components and the pistons. The advantage of this design is the flexibility of the pistons and their ability to handle components of diffferent height and the non-planarity of components. The BGA package has a very wide tolerance range.

To allow the blocks with pistons on the underside to pass through for assembly of the short-finned heat sink, the mother board was designed with a routed opening in front of the four TAB tapes, Fig. 10.

The heat sink casing gives the module a height of 45 mm on the top side and 6 mm on the underside, Fig. 11.

This versatile design for heat management is very flexible and can be of use in many future products.

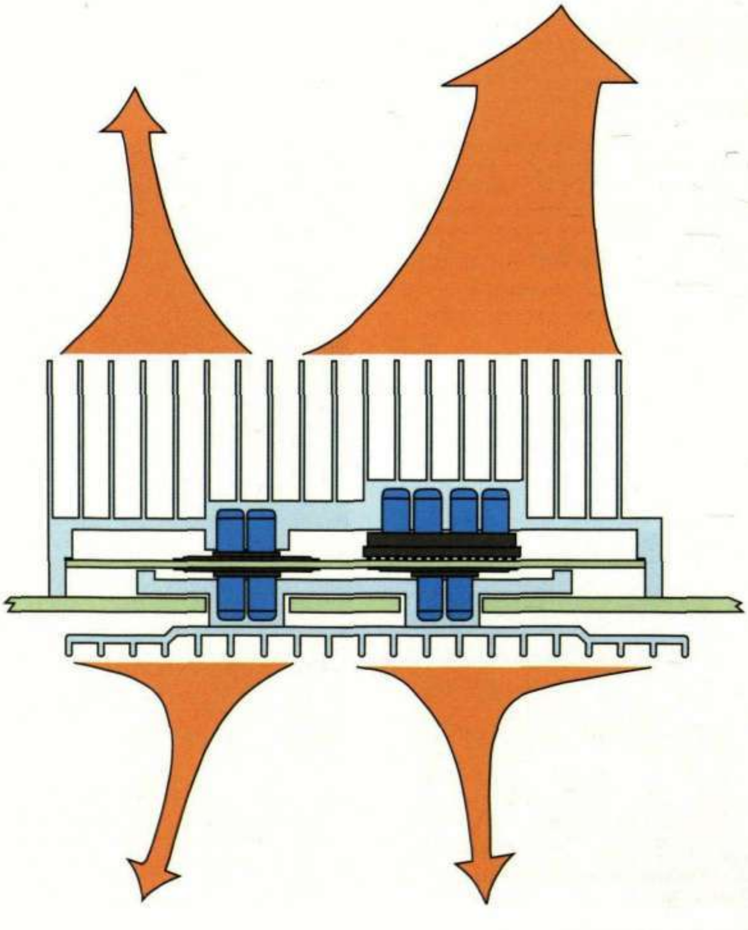


Fig. 10
Cross-section of the final product with heat sink. The arrows indicate the heat dissipation from the module

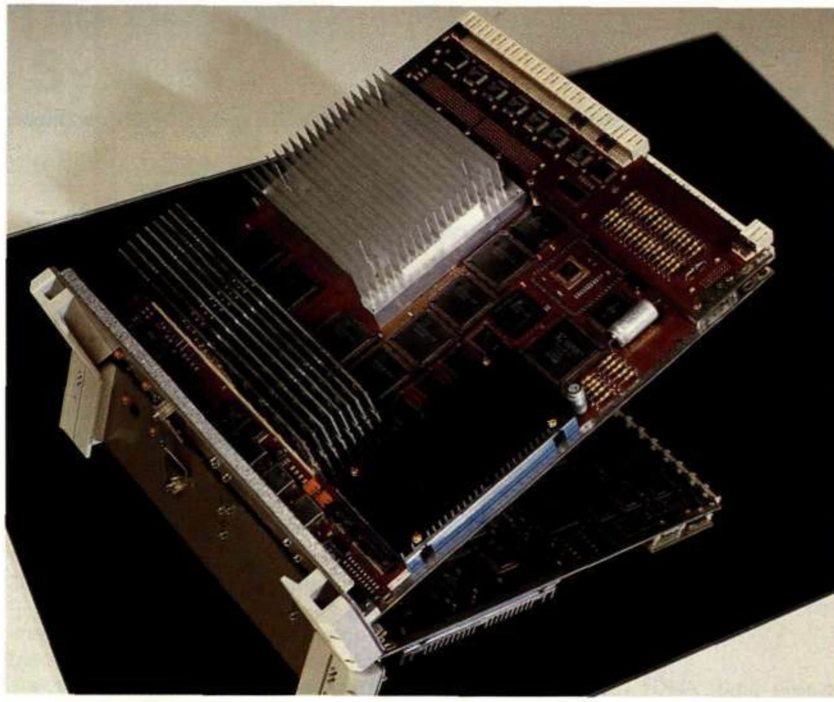


Fig. 11
The final product assembled on the mother board. The underside of the mother board can be seen in a mirror

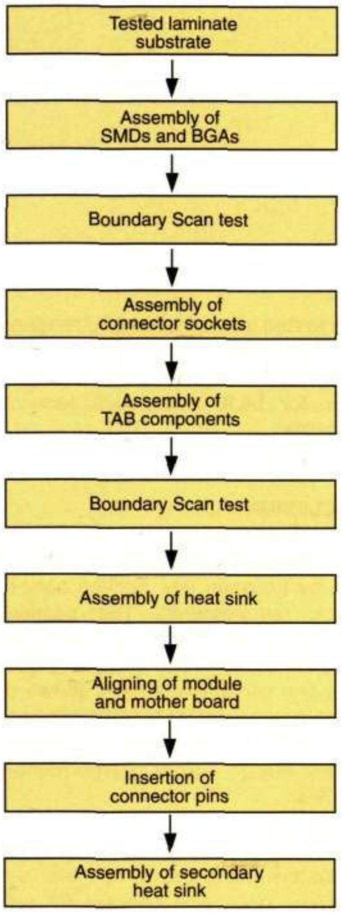


Fig. 12
Flowchart for assembly and test of module

SYSTEM EVALUATION

Most of the system design, as well as the performance of the final product, has been verified in the laboratory. The module has met the specified electrical requirements when tested at different clock speeds. Seven modules with assembled heat sink have been running for six months in different full-speed tests. The thermal design has fulfilled the stringent heat-dissipation requirements.

The satisfactory results have encouraged the system designers to consider the same packaging concept for future products with even higher clockspeeds.

TEST STRATEGY

The final product is a high-performance module that will be produced in small volumes.

The objectives of the module test strategy are as follows:

- detection and isolation of defects in manufacture

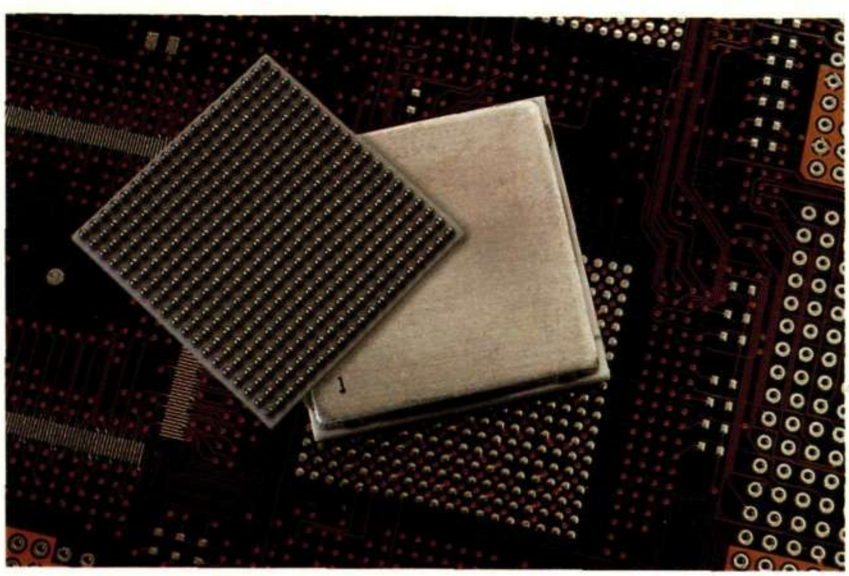


Fig. 13
Ball Grid Array package, with 361 solder balls with a 1.27 mm pitch

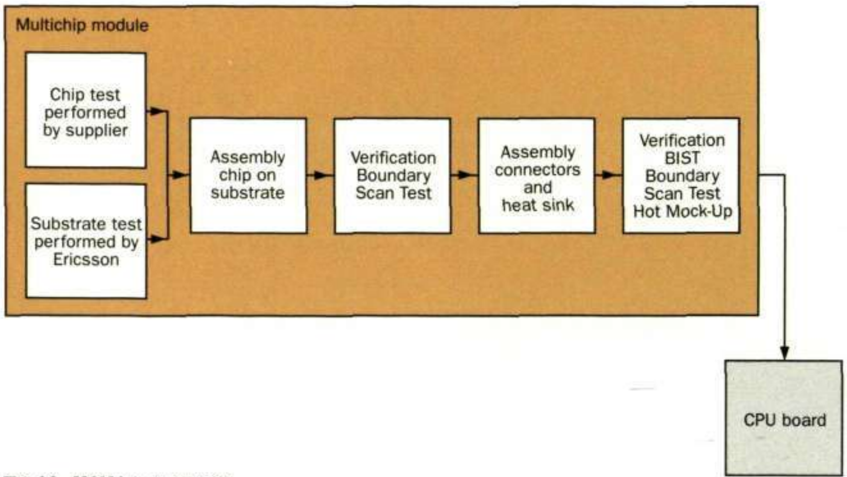


Fig. 14. MCM-L test strategy

– performance verification of the assembled module before delivery to board assembly and system production.

The test flow is briefly described below, and in Fig. 14. The test strategy is presented in detail in Ref. 3.

MCM interconnect test

A Boundary Scan test is performed on the partly and completely assembled module in the production flow. The test will detect any manufacturing defects in chip interconnections and module inputs and outputs.

MCM limited functional test

The purpose of the MCM limited functional test is to verify – on the basis of selected parameters and/or functions – the performance of the module at operating speed. The test equipment can be either a Hot Mock-Up or an MCM Tester. Hot Mock-Up is a test at system level; the module is tested in a modified CPU magazine. The MCM Tester is based on a VLSI Tester upgraded with software from a board tester for fault diagnostics/back-trace capabilities.

CONCLUSION

The packaging concept for the RISC processor application designed and manufactured by Ericsson has fulfilled specified system requirements. The packaging design has been made in close cooperation with system and ASIC designers. Tests and verifications have shown that available technologies for ASIC packages, substrates and assembly – combined with efficient design – yield high-performance modules.

The satisfactory results have encouraged the system designers to consider using the same packaging concept for future products with even higher clock speeds.

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D-AMPS 1900 – The Dual-Band Personal Communications System

Magnus Isaksson, Antony Bacon and Egil Grönstad

For new and existing wireless operators, D–AMPS 1900 – the dual-band 800/1900 MHz standard – meets the PCS requirements for time-to-market, backward compatibility, and cost-effective deployment. The dual-band technology used in the design of terminals and networks offers the end user unique roaming capabilities within all existing cellular markets as well as new D-AMPS PCS markets. The ability to roam between frequency bands means that new PCS operators can offer nation-wide, seamless coverage from day one, and enables cellular operators to offer PCS service in their existing markets.
The authors describe the dual-band standard and how it benefits PCS systems in North America and in the rest of the world.

The emerging personal communications services (PCS) are expected to transform today's cellular service offering into a highly differentiated, mass-market product appealing to a wide range of new subscribers. Operators will rely on cost-effective, commercially proven technologies and system solutions. Key characteristics are increased capacity, high voice quality, feature-rich functionality, indoor/outdoor coverage, and seamless roaming.

In North America, TDMA (time division multiple access) digital cellular systems built according to the D-AMPS standard (IS-54) have been in commercial operation since 1992. Today, D-AMPS systems are deployed in several countries in America, Asia and Oceania. D-AMPS has already proven to be a highly evolvable standard with a superior level of network interoperability via the IS-41 network standard.

Fig. 1
PCS is seen as a low-cost mobile communications service, based on lightweight pocketphones targeted at the ordinary end-user

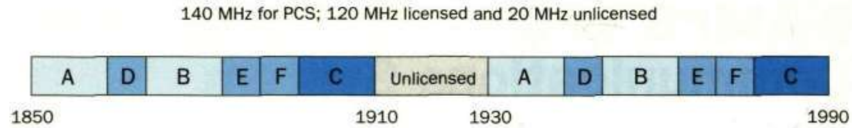


Fig. 2
Spectrum allocation for PCS in the US

A, B	2 x 15 MHz MTA
C,	2 x 15 MHz BTA
D, E, F	2 x 5 MHz BTA

Major manufacturers from both the US and the rest of the world are marketing D-AMPS systems for world-wide use. Currently, AMPS/D-AMPS accounts for 60% of the total number of cellular subscribers.

THE PCS INITIATIVE

The approach towards personal communications in the US is unique. PCS has been defined as a concept – without reference to any specific technology. In 1990, the Federal Communications Commission (FCC) issued a Notice of Inquiry, in which PCS is described as encompassing "a broad range of radio communications services that free individuals from the constraints of the wireline PSTN and enable them to communicate when they are away from their home or office telephone."

During 1994, FCC allocated spectrum in the 1900 MHz (1850-1990 MHz) band for PCS in the US, Fig. 2. It was decided that PCS licences should be sold by public auction. USA was divided into 51 Major Trading Areas (MTA) and 492 Basic Trading Areas (BTA). Two licences are issued for each MTA and four for each BTA. In total, 2074 licences will be issued in 1995. Regulatory bodies in other countries have followed suit and allocated these frequencies for PCS.

Existing North American 800 MHz cellular operators are allowed to acquire 10 MHz of the available spectrum for PCS in their service area, and 40 MHz outside this area.

A high cost of PCS licences means that successful bidders will require that their networks be operating as quickly as possible. The competition faced by PCS operators will be fierce, and it will be vital for them to offer new and innovative services to differentiate them from their competitors.

PCS can be seen as both a threat to and an opportunity for the current 800 MHz cellular operators. The threat comes from the new PCS licencees, who will start competing with the cellular operators in their present service areas. To meet this threat, the cellular operators are expected to improve the coverage and quality of their service, introduce new tariff models aimed at private users, and introduce new features for business users. In effect, they will be offering personal communications services using their 800 MHz cellular licence.

The opportunity stems first and foremost from the possibility of acquiring PCS licences in areas where an 800 MHz cellular operator is not providing service today. In this way the cellular operator will increase his service offering to new markets; that is, increase his footprint. If he chooses a dual-band technology, the users will be equipped with handsets that function in both 800 and 1900 MHz systems without the user noticing any difference.

D-AMPS 1900 – THE DUAL-BAND STANDARD FOR PCS

D-AMPS is an existing TDMA-based digital standard in world-wide commercial service at 800 MHz. Standardisation of D-AMPS in the Telecommunications Industry Association (TIA) in the US has been approached in phases, for various reasons[1]. The first phase (IS-54) aimed at increased capacity, backward compatibility and short time-to-market. Backward compatibility, in this context, means that existing analog phones can be – and are – supported in digital D-AMPS networks too. The second phase (IS-136) focused on new features and other end-user benefits.

D-AMPS (IS-54)

D-AMPS systems in commercial service are based on the TIA standard IS-54. It is a dual-mode standard that allows both analog AMPS and digital D-AMPS services to be offered in the same network. D-AMPS phones are also dual-mode; services are provided via either analog or digital access networks for maximum flexibility.

The first phase of D-AMPS offers more than three times the capacity of a standard analog AMPS system. The Ericsson implementation of D-AMPS gives operators total flexibility when it comes to migration from analog to digital. Furthermore, because digital channels can be easily added to existing analog systems, any number of analog channels can be made digital without any service interruption. This gives network operators the freedom to choose the speed and timing of their digital introduction. With the latest Ericsson radio base station, RBS 884[2], transceivers can be changed from analog to dig-

Fig. 3
Dual-band D-AMPS pocketphones give the end-users unique advantages compared with other technologies

ital mode by a command in the mobile services switching center (MSC).

Digital control channel (IS-136)

The D-AMPS standard applicable to PCS networks at 800 MHz – designated IS-136 – introduces the digital control channel[1] for support of new applications and teleservices. It enables operators to provide personal communications services, such as short message service and sleep mode capability, which will dramatically increase both the functionality and the battery life of PCS phones. In addition, the second phase of D-AMPS will allow hierarchical cell structures to be implemented, facilitating the introduction of private systems, differentiated service and charging areas while increasing the overall capacity of the system.

The Ericsson implementation of IS-136 has been designed to allow simple system integration by software upgrade of the existing IS-54 based D-AMPS networks to IS-136. This solution provides an excellent evolution path for AMPS operators to migrate into digital cellular and then into the PCS arena while protecting their capital investment.

D-AMPS 1900

D-AMPS 1900 has been specified in the US as a dual-band PCS technology for the 800 and 1900 MHz bands. This enables dual-band terminals to support both 800 and 1900 MHz with full national/international roaming and feature transparency. The D-AMPS 1900 standard – designated as J-STD-011 by the American National Standards Institute (ANSI) – is an up-banding of IS-136, with the dual-band 800/1900 MHz capability added to pave the way for nation-wide systems. D-AMPS 1900 is an excellent technology for PCS networks.

The Ericsson implementation of D-AMPS 1900 allows radio base stations for 800 and 1900 MHz to be connected to one and the same MSC. In fact, 800 and 1900 MHz transceivers can operate from the same base station site, reusing some existing base station infrastructure.

The two phases of D-AMPS at 800 MHz – IS-54 and IS-136 – as well as D-AMPS 1900 are implemented in one and the same Ericsson system: CMS 8800.

THE DUAL-BAND CONCEPT

Dual-band 800/1900 MHz capability offers

- identical PCS applications and transparent delivery of end-user services to subscribers operating in both bands,
- homogeneous switch network for 800 and 1900 MHz services,
- seamless interworking between 800 and 1900 MHz networks through dual-band mobile stations.

For a PCS operator, this offers a number of immediate advantages. Existing 800 MHz infrastructure can be used for 1900 MHz services as well, for a cost- effective and quick service offering. Roaming and handoff between 800 MHz and 1900 MHz D-AMPS networks are supported.

New operators at 1900 MHz

For operators at 1900 MHz, the dual-band capability means nation-wide, seamless coverage offered to the end-users from day one through roaming agreements with 800 MHz operators, or other 1900 MHz operators, in different geographical areas. The concept is illustrated in Fig. 4.

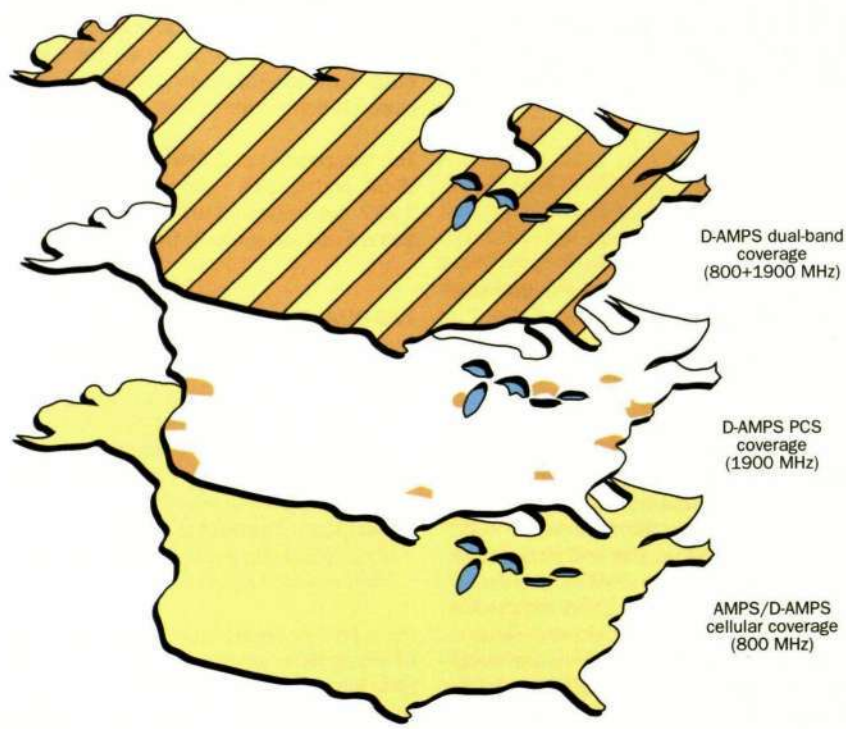
Existing operators at 800 MHz

Existing 800 MHz D-AMPS operators can use the 1900 MHz spectrum to increase capacity and develop new user segments in their 800 MHz networks. For example, 800 MHz cells can cater for wide-area coverage and serve as umbrellas for 1900 MHz microcells and picocells. The small cells can cover indoor office environments, shopping malls and airports, and provide difficult-spot coverage. The umbrella cells can cater for fast-moving users and users who are moving between two isolated microcells.

REUSE OF CURRENT CELLULAR INFRASTRUCTURE

Dual-band capability means that only some cell site equipment needs to be implemented to start up a PCS offering at 1900 MHz. Existing MSCs in 800 MHz networks can be used to introduce new PCS services at 1900 MHz. Existing radio base station sites for 800 MHz can be used, which means saving on real estate, power, tower, transmission, and site costs. Three different scenarios are shown in Fig. 5. A quick service offering can be achieved by back-hauling 1900 MHz base stations in new coverage areas to the existing switching network. Operational handling can be made more cost-effective by using the same operations support system (OSS) for 800 MHz and 1900 MHz networks.

Fig. 4
Nation-wide seamless coverage from day one



APPLICATIONS AND FUNCTIONALITY

PCS will exist in many different environments, e.g. wide-area coverage, the wireless office, and as an equivalent to PSTN in a residential setting. To be competitive, a PCS system must have a high degree of functionality and flexibility. Through the deployment of the digital control channel[1], D-AMPS 1900 offers full PCS functionality including the features listed below.

Mobile intelligent network (IN)

Mobile IN capabilities offer fast and flexible creation of advanced subscriber features, such as personalised numbering, time-based forwarding services, and business groups[3]. Mobile IN means unlimited possibilities for an operator who wishes to differentiate his service offering to gain a competitive edge on his rival operators.

Location based services

Location-based services permit the operator to apply different charging rates and assign them to end-users based on their location. Charging can be differentiated, e.g. low charge for home and office, and premium charge for wide-area use. An alphanumeric system name or greeting banner can be displayed on the terminal to inform the end-user of which tariff level will be used.

Messaging

Short message services (SMS) can be used for one-way or two-way messaging

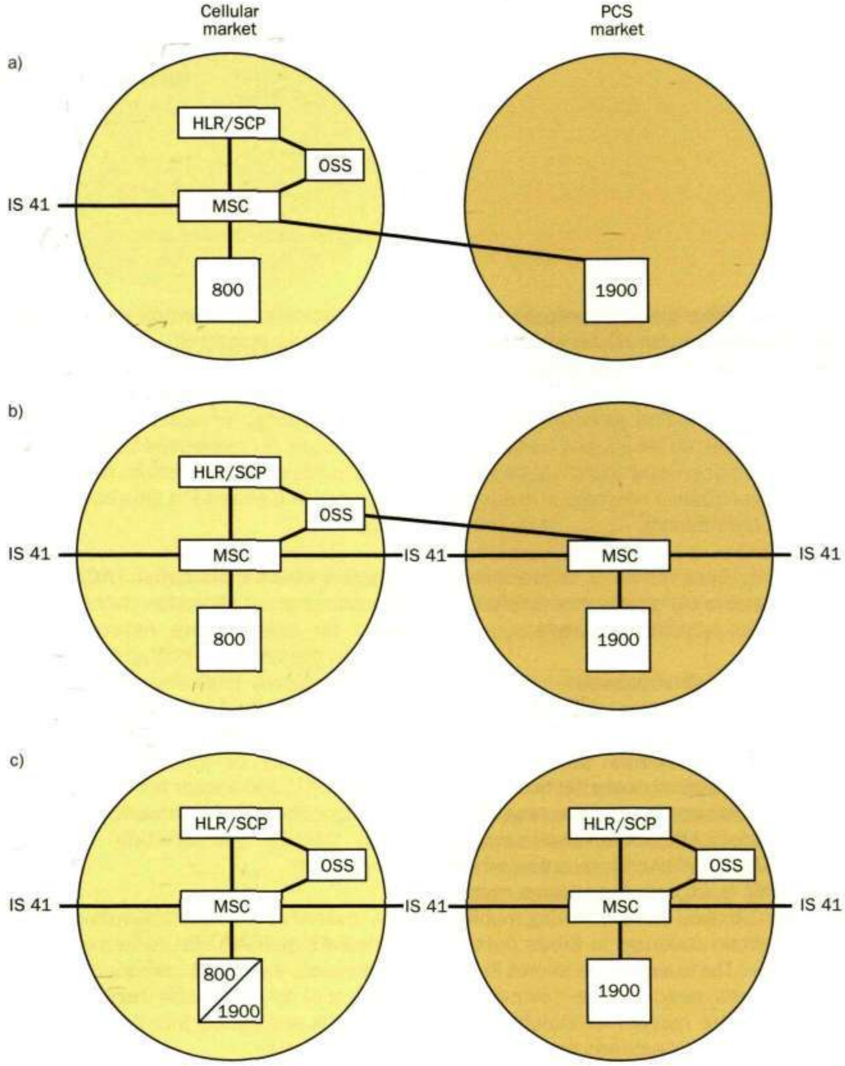


Fig. 5
Optimum use of current cellular infrastructure

a) Back-hauling of 1900 MHz base stations in new coverage areas to existing switching network.

Using existing switching equipment through software additions

b) Utilizing the same operations support system (OSS), home location register/service control point (HLR/SCP) and billing systems for both bands.

c) Making use of existing radio sites by integrating 1900 MHz radio equipment

HLR/SCP	Home location register/service control point for mobile IN
OSS	Operations support system
MSC	Mobile switching center
800	Base station 800 MHz
1900	Base station 1900 MHz

between subscribers. SMS messages can be sent to a subscriber even when he is using his phone. This is a convenient way of getting an urgent message through to a busy subscriber. SMS broadcast services can also be used by operators to broadcast – traffic information, for example – either to selected areas or to a specific group of subscribers.

Data services

High-speed asynchronous data (up to 28.8 kbps) and fax G3 capabilities are supported by D-AMPS systems. The use of data compression techniques increases the possible transfer speed even further. Interfaces are provided for a variety of networks, e.g. packet switched data networks. This allows for the realisation of the mobile office, i.e. having access to e-mail and fax capabilities when away from the office.

Security

Terminal authentication prevents fraudulent usage by protecting both the operator and the subscriber. The authentication incorporated in D-AMPS uses a secret key stored in the phone and in the auhentication centre in the network. The secret key is never transmitted anywhere in the network; a shared secret data element (which cannot be used to reveal the secret key) is used instead. Voice privacy offers cryptographic protection against eavesdropping between radio base stations and the mobile, to further increase the security level in the network. Even without this voice privacy feature, the use of digital TDMA technology ensures a high level of protection.

High voice quality

The basic voice quality in D-AMPS is superior, and this is one of the key factors for a competitive and successful network. For especially demanding applications – office applications, for example – enhanced vocoder technologies can be used to further increase the voice quality.

Networking and transmission

ISDN networking between PCS and public and private networks offers a high degree of service transparency. Service and transmission costs can be reduced by introducing remote switching points or local switching. This is of interest in wireless office and large campus applications. The transmission of mobile-to-mobile calls within an office need not extend outside the office building, which reduces the need for costly transmission links.

Sleep mode

Extended terminal battery service life is achieved through sleep mode.[1] Sleep mode means that when the phone is idle, it will automatically be turned off and periodically "wake up" to check if there are any paging messages for it. Up to 120 hours of standby time will be offered, which is a substantial increase.

COVERAGE AND CAPACITY

There are four key concepts that will help operators to achieve coverage and capacity, and at the same time reduce operational costs.

Microcells

Microcells will be a major part of a competitive PCS concept. Typical applications are indoor office environments, shopping malls, airports, subway stations, and difficult-spot coverage. Capacity, coverage, increased talk-time for pocket phones, low cost and easy-to-find sites are powerful market drivers, as are indeed certain zoning restrictions (operators' putting up antennas on roofs, for example, is subject to many restrictions).

A capacity increase 5-10 times over a system consisting of only macrocells can be achieved by using microcells

Hierarchical cell structures
Hierarchical cell structures mean that large macrocells are overlaid by small microcells. Hierarchical cell structures represent merely a cost-effective way of deploying microcells, and the reason for this is twofold. Microcells can be used for slow-moving traffic and in areas where high traffic is expected; and large macrocells can be used for fast-moving mobiles and to obtain coverage in areas outside microcells. The main idea is shown in Fig. 7. Microcells need not be "overdimensioned": if the number of simultaneous calls in a microcell exceeds the number of voice channels, the overflow traffic can be carried by the macrocell.

Hierarchical cell structures also facilitate flexible charging. For example, a lower rate can be used for microcells that cover an office building and a premium rate for the macrocell that serves the area outside the office.

Adaptive channel allocation (ACA)
Adaptive channel allocation (ACA) is a key factor for cost-effective networks. ACA reduces the need for frequency planning by automatically analysing, learning, and deploying the most efficient frequencies for digital traffic channels. This increases system quality by reducing co-channel interference, and a potential for increased capacity in the cellular network is also provided through the addition of more transceivers.

ACA makes for very robust systems. It has immediate, positive effects on a system's voice quality and on its operational costs. It is a tool for large-scale deployment of microcells and greatly facilitates the adding of new sites.

Fig. 6
PCS opens up possibilities for operators to penetrate new market segments successfully

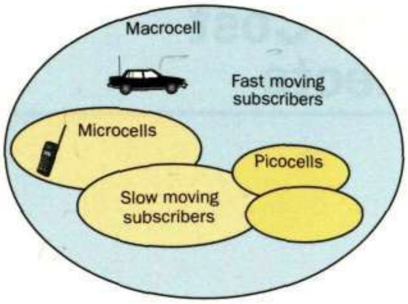


Fig. 7
Hierarchical cell structures for virtually unlimited capacity

Intelligent antennas
The intelligent antenna is a product for cost-effective wide-area coverage in PCS networks operating at 1900 MHz. Its basic function is to extend the cell range, and it is therefore well suited for rural and suburban application. It allows operators to take full advantage of FCC rulings of 1640 W EIRP (equivalent isotropically radiated power) base station output power. The intelligent antenna is capable of balancing this output power and that of ordinary pocketphones: 0.6 W.

Intelligent antennas allow wide-area coverage solutions to be implemented quicker and at a lower cost. This is because the number of sites required to cover an area is reduced by around 40%. It results in great savings on radio base station equipment, conventional antennas and towers, real estate costs, transmission facilities, and operation costs .

It is believed that site acquisition will become even more difficult in the next few years. The intelligent antenna will be of great help to operators in this respect, by reducing the number of sites.

SUMMARY
D-AMPS 1900 – the dual-band 800/1900 MHz system – meets the PCS requirements for time-to-market, backward compatibility, and cost-effective deployment. The dual-band capability of terminals and networks enables new PCS operators to offer nation-wide, seamless coverage from day one. D-AMPS 1900 offers a feature-rich functionality for subscriber differentiation, and optimum use of current cellular infrastructure. Capacity is virtually unlimited through the use of hierarchical cell structures, microcells and adaptive channel allocation, which also significantly reduces operational costs.

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The Apollo Demonstrator – New Low-Cost Technologies for Optical Interconnects

P. Eriksen, K. Gustafsson, M. Niburg, G. Palmskog,
M. Robertsson and K. Åkermark

New types of services, such as multimedia communication, video-on-demand, etc, will require increased transmission capacity in transport networks, switches and access networks.
Handling of vast amounts of data within the telecom equipment by means of traditional electrical technology becomes a very difficult and – at a certain point – an impossible task. Optical interconnects offer a possible solution, provided that the costs of introduction of this technology are affordable for both system operators and service users.
The most serious obstacle to achieving a cost-effective total solution lies in the very high costs for packaging and alignment of optoelectronic modules and components, a problem that might be solved by using non-hermetic plastic packaging techniques.
Other critical factors in future "fibre-rich" networks are easy installation and maintenance of optical cables and connectors. Some possible solutions to these problems, presented in the following, are fibres laminated in the flexfoils and polymer waveguides patterned on flexfoils or on printed circuit boards.
The authors review some ongoing applied research (AR) activities at Ericsson aiming at reduced costs and enhanced performance of optical interconnects. They describe Apollo, an AR project for a complete subsystem of parallel optical interconnects.

Increased throughput and flexibility in large-scale electronic equipment creates a need for increased interconnection density and capacity. The growing demand for new broadband interactive telecom and computer services is expected to enforce this development, which presents a challenge to traditional electronic interconnection technology and an opportunity for new optical solutions.

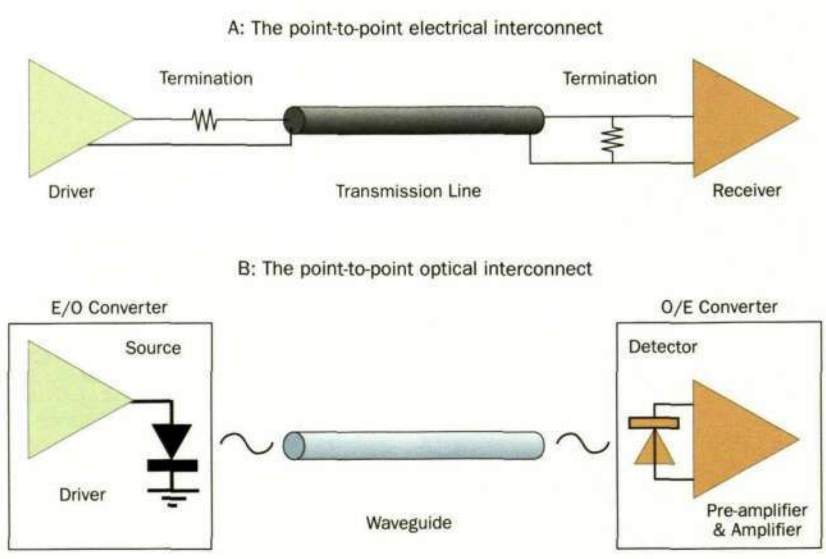
Nowadays, optical fibre has almost completely replaced copperwire for long-haul transmission because of its superior capability of supporting high bandwidth over long distances. The introduction of optical solutions improves system performance even for the short distances that typify interconnect applications. Distances, corresponding to the different levels of the interconnection hierarchy, are shown in Box A.

There is a number of advantageous features, listed in Box B, which make optical interconnects an attractive alternative, especially for bitrates in the Gbit/s range, where electrical interconnects reach some practical and fundamental limits.

The principal difference between point-to-point electrical and optical solutions is that, in the latter case, electro-optical (e/o) and opto-electrical (o/e) conversion is required, as illustrated in Fig. 1. This increases costs, complexity and power consumption.

The main reason for the relatively moderate use of optical technology today is cost. Reliability and serviceability are other frequently mentioned factors of uncertainty.

Fig. 1
Electrical (A) and optical (B) point-to-point interconnects. The principal difference between point-to-point electrical and optical solutions is that the optical case requires electro-optical (e/o) and opto-electrical (o/e) conversion



Box A

Classification of interconnection levels (with respect to max. length) within the area of telecom applications

1.	chip-to-chip	(intra-module, intra-board)	0,1 m
2A.	module-to-module	(inter-module, intra-board)	1 m
2B.	board-to-board	(inter-board, intra-subrack)	3 m
2C.	board-to-board	(inter-subrack, intra-cabinet)	5 m
3.	board-to-board	(inter-cabinet, intra-office)	200 m
4. (+access)	board-to-board	(inter-cabinet, office-to-access terminal)	20 km

Box B

Benefits of using optical interconnects

- electrical isolation and immunity to EMI (electromagnetic interference)
- much (several orders of magnitude) smaller and frequency-independent loss and thus extendibility to longer distances
- much (several orders of magnitude) smaller size and weight of cables and connectors
- higher connection density at the edge of the printed circuit board (PCB) in cases where crosstalk and line resistance in electrical microstrip lines on the PCB become limiting factors
- lower skew (difference in propagation time between channels), which is important in the case of parallel links.

When these problems are solved, a vast range of applications would be available, including:
- telecommunications
- datacommunications
- avionic and automobile industries.

In the following, only telecom applications and requirements are discussed. But datacom requirements should also be met, to the greatest possible extent, since this would entail production volumes large enough to bring down the price of optical interconnects to a competitive level.

Possibilities of applying optical interconnects for telecom applications have been proved by a number of existing products, e.g. Ericsson's OPTAX link. This is a serial link, i.e. data is transmitted through a single optical fibre.

Another possible interconnection solution is a parallel approach. Here, in contrast to the serial solution, data is transmitted through multiple optical channels (fibres), Fig. 2. This solution employs either a number of discrete components or more compact and cost-effective "array" structures for laser diodes (LDs) and PIN diodes, as well as ribbon fibre and multifibre connectors.

The parallel link can be used in two different ways: synchronously (bit-parallelly) and asynchronously.

In the synchronous mode of operation, signals in all the channels are kept "in phase", so that a single clock channel can be used to clock out all the signals. Here, all the benefits of the parallel concept can be most effectively used, provided that

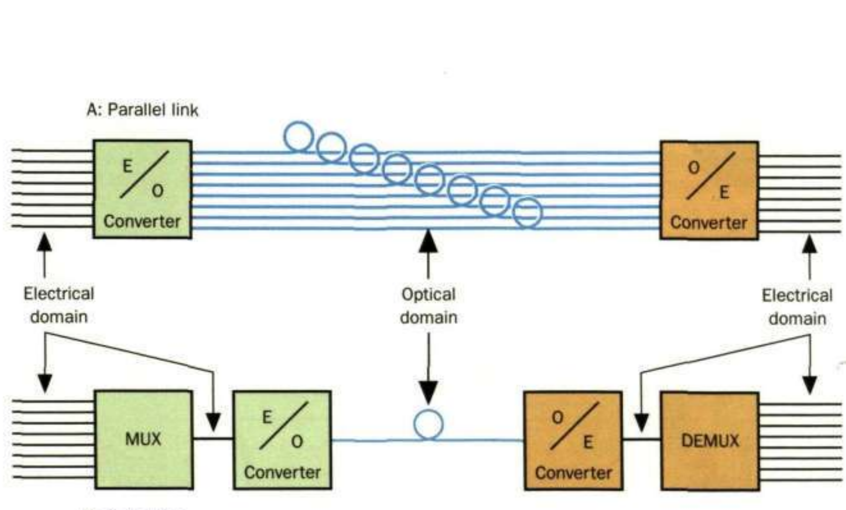


Fig. 2
The parallel (A) and the serial (B) concepts of optical interconnects. In a parallel link, data is transmitted through multiple optical channels (fibres). A serial approach employs a single optical channel (fibre)

Box C

Advantages and disadvantages of using a parallel solution, compared with a serial solution

Advantages:
- lower cost per Gbit/s, mainly since encapsulation and assembling costs are shared between several channels
- higher packaging density on both the surface and at the edge of a PCB, due to much smaller mechanical size of array components, compared with a corresponding number of discrete components

(These two advantages refer to the use of dense "array" structures, in both synchronous and asynchronous modes of operation, compared with the use of discrete components)

- lower power dissipation and less complex electronics, since no MUX/DEMUX function and no clock recovery are required

(This refers to the use of a parallel synchronous solution, compared with a corresponding serial solution according to Fig. 2)

Disadvantages:
- electrical and possibly optical and thermal crosstalk
- reliability issues, since a single degraded element in an LD array brings down the whole module
- skew in fibres and electronics

inter-channel skew (difference in propagation time between channels) is carefully controlled.

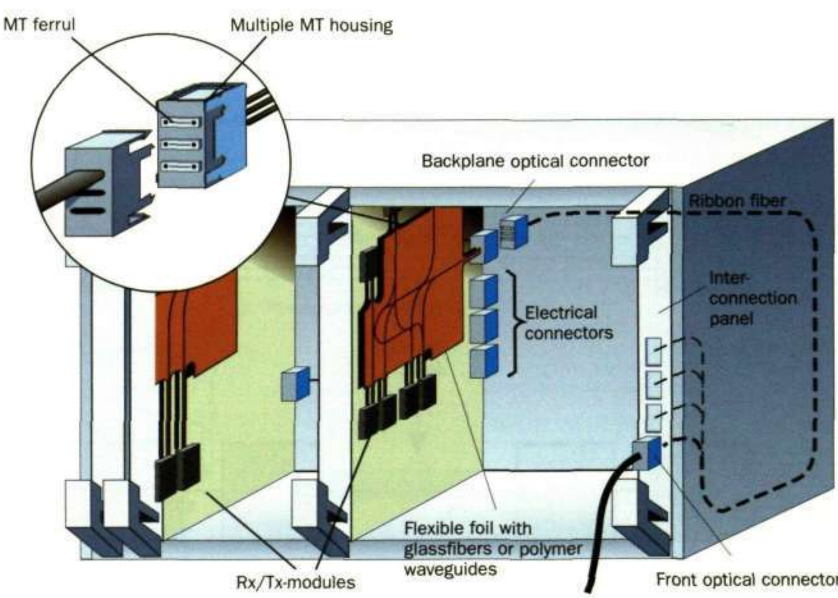
In the case of asynchronous mode of operation, the individual channels are time-independent, and the common clock is not applied. The advantages of compactness ("concentration" of LDs, PIN diodes and fibres) and cost reduction still remain.

Both the serial and the parallel concept have their pros and cons. Some of them are shown in Box C.

Serial solutions are already available as commercial products thus having the advantage of proven functionality and reliability.

Parallel links are less established, but all over the world much work has gone into the development of this concept because it is expected to provide an important breakthrough in terms of cost and performance.[1, 2, 3]

Fig. 3
The Apollo demonstrator – a schematic view. All communication at the cabinet and subrack levels is handled via a separate optical interconnection panel on the side of the subrack, to which all incoming and outgoing cables are connected. Communication between printed circuit boards is routed via the backplane



THE APOLLO DEMONSTRATORS

Currently, both serial and parallel concepts are under investigation at Ericsson. This article describes an applied research project, called Apollo (Advanced Packaging of Optical Links, Logics and Optoelectronics), which aims at the development of a total sub-system of parallel optical interconnects: i.e. the link itself and the equipment practice which surrounds and supports the link.

The project will result in two demonstrators. Demo/1, which mainly exhibits equipment practice, was completed at year-end 1994. Demo/2 will contain several operational links and will be completed in mid-1996.

System requirement

The Apollo specification is mainly targeted at achieving:

- low cost per Gbit/s of transmitted data
- low power dissipation per Gbit/s
- high interconnection density and small mechanical size
- high reliability

The predicted performance and the total cost of future systems is considered in the specification, as well as the cost and performance of competing electrical solutions. The most important requirements are listed in Box D.

The two ranges of distance specified in Box D correspond to the values required by intra-office and central office-to-access terminal interconnects (see levels 3 and 4 respectively in Box A).

The access application specifies use of a singlemode fibre, SMF, as the interconnection medium, while intra-office interconnects could be implemented with either multimode, MMF, or SMF fibre. The choice of fibre makes a very important difference in terms of necessary alignment tolerances (several μm for MMF and tenths of μm for SMF) and has a huge impact on the resulting costs. The skew (difference in propagation time between channels) is another parameter that influences the choice of fibre. The skew is lower in SMF than in MMF.

An important issue is the choice of wavelength of LD emission. Today, short-wavelength LDs (around 800 nm) are much

Box D

General specification of the Apollo link

Characteristics	Value, description
Cost/Gbit/s	max 100 USD (for interconnects; MMF or SMF can be used) max 200 USD (for access; SMF is required)
Power dissipation/Gbit/s	max 1.0 W
Area on PCB/Gbit/s	max 1.5 cm^2
Data rate per channel	min 100 Mbit/s max 800 Mbit/s
Number of channels	min 2 max 12 (the current MT standard)
Optical dynamic range	approx. 20 dB
Input signal level	differential, LVDS-compatible
Power supply	+3.3 V
BER	better than 10-14
Case temperature	max 75°C
Relative humidity	max 85%
Lifetime	min 20 years
Distance	max 200 m (interconnects, synchronous case, with one common clock channel) max 20 km (access, asynchronous case, with no common clock; SMF is required)

cheaper and less temperature-dependent than 1300 nm LDs, but their lifetime might not be sufficient for telecom applications. The 1300 nm wavelength is also required if SM transmission using conventional SMFs has to be ensured. Surface-emitting LDs are promising because of the favourable (spherical) emission geometry, which gives better coupling efficiency. An additional advantage is that they can be tested directly on wafer, but this technology is not fully verified.

The main track for the link today is a 1300 nm edge-emitting low-threshold LD array. Low threshold current in the LD is very important, since
- it makes it possible to use zero or very low bias and low modulation currents, which gives low power dissipation and at the same time ensures short turn-on time delay, i.e. low skew
- it results in higher reliability, because of low current density in the active area.

In order to achieve sufficiently low threshold currents, LD arrays with multiple quantum well (MQW) structure are most likely needed. Another important structural feature, required in the actual application, is "p" or semi-isolating types of substrate, since they permit optimal LD-driving by n-p-n transistors.

An important feature of the link is its large optical dynamic range of approx. 20 dB, which is an absolute requirement in the case of access networks, where distances up to 20 km have to be covered. Even for interconnect applications it offers an advantage of handling:
- larger variations in optical power and thus relieving the requirements that apply to alignment tolerances, degradation, etc.
- larger optical power budget, thus allowing a larger number of connector interfaces and the use of relatively lossy polymer fibres and waveguides.

The transmitter and the receiver circuits are designed in an 0.5 µm BiCMOS process EPIC3B, which is available at Ericsson's new fab in Kista, Stockholm.

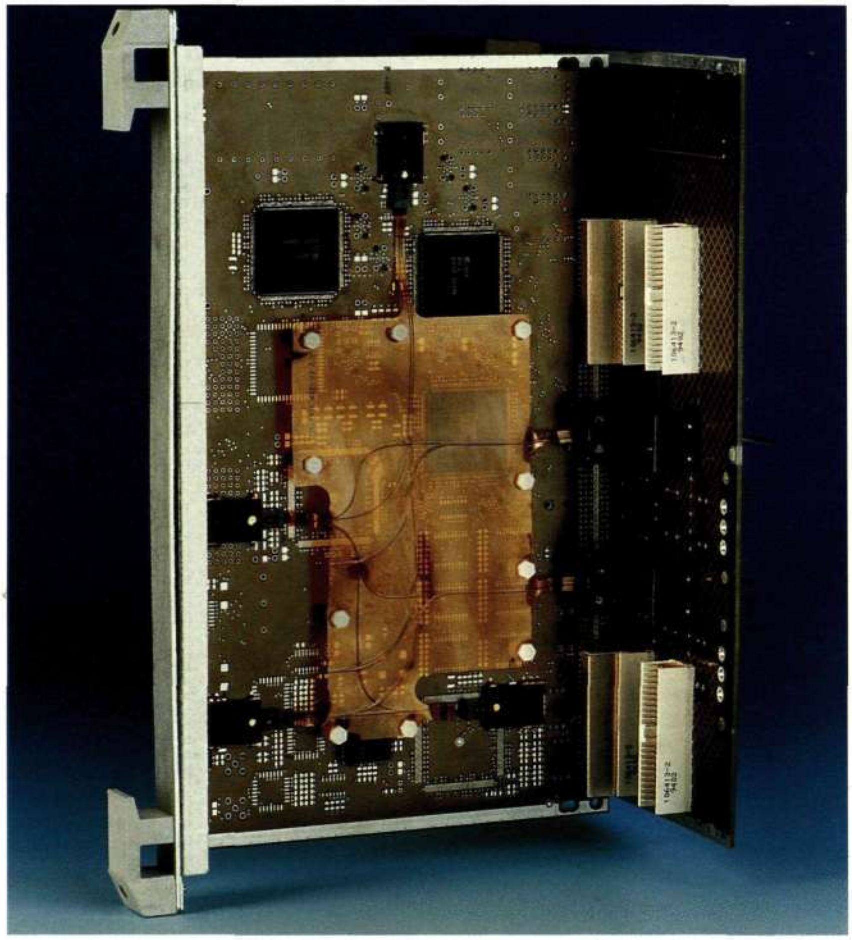
One possible solution implies AC-coupled design, internally within the link, while from the outside the link can be regarded as DC-coupled (input data "transparent"), i.e. it puts no requirements on DC balance etc. The AC internal coupling provides:
- higher sensitivity, which gives both lower power dissipation and larger dynamic range
- lower skew, which extends the range for synchronouos operation.

Apollo demo/1 for future optical equipment practice

Apollo demo/1 is schematically shown in Fig. 3. The large dynamic range of the link allows the use a sophisticated equipment practice, in which all communication at the cabinet and subrack levels is handled via a separate optical interconnection panel on the side of the subrack to which all incoming and outgoing cables are connected.

Communication between printed circuit boards, PCBs, is routed via the backplane. This permits any PCB to be removed without the need to disconnect optical cables. The solution also provides a "clean" front, which is demanded by more and more operators.

Fig. 4
A printed circuit board (PCB) in the Apollo demonstrator. The actual PCB contains a "flexfoil" for fibre handling. Opto-electrical modules with an MT (mechanical transfer) optical interface are shown, as well as backplane MT-connector housings



One of the PCBs in the demonstrator is shown in Fig. 4.

An MT (mechanical transfer) compatible interface has been chosen as the optical interface for both modules and connectors. The external sourcing of these components is secured, since MT is an international standard.

The MT connector, Fig. 5, has also been chosen for two other reasons: it is adapted to high-density multifibre (ribbon) cables, and it has a potential for reducing

Fig. 5
MT-compatible optical connector for multi-fibre applications. MT connectors in the Apollo demonstrator are moulded directly on fibre by a technique developed at Ericsson.
A multimode performance level has already been achieved, giving an insertion loss (IL) of less than 1 dB. A cost reduction of 70%, compared with the conventional mounting technique, can be obtained with this method

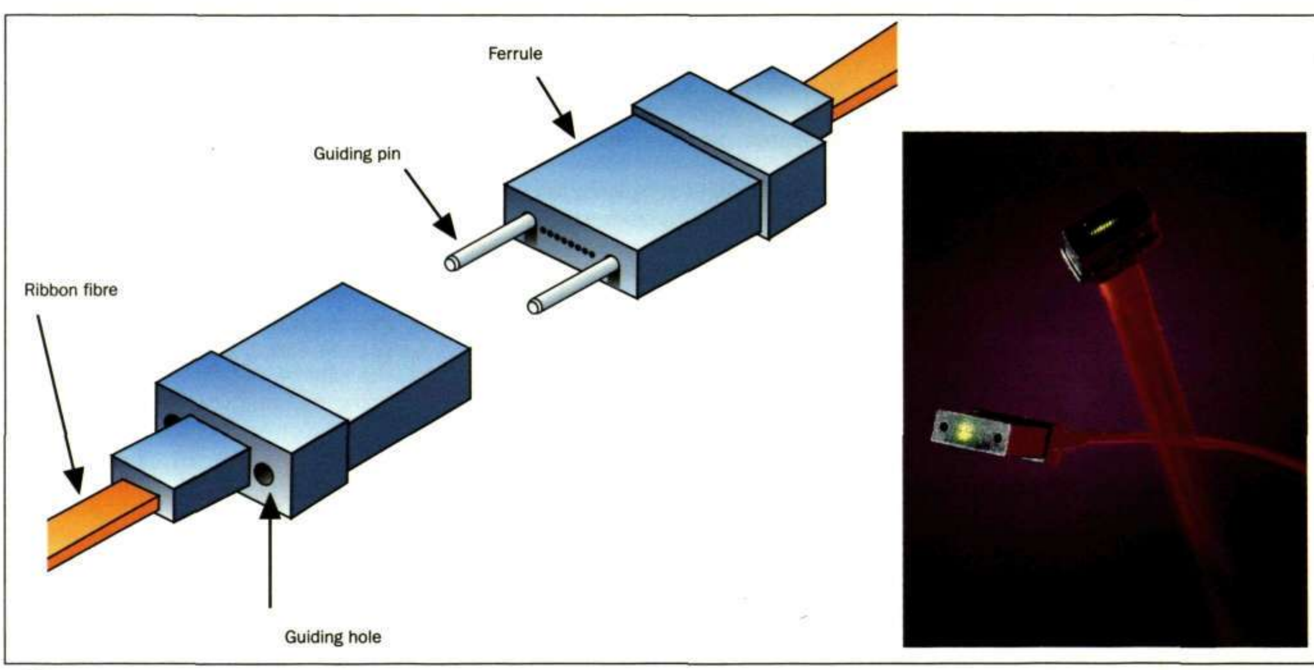
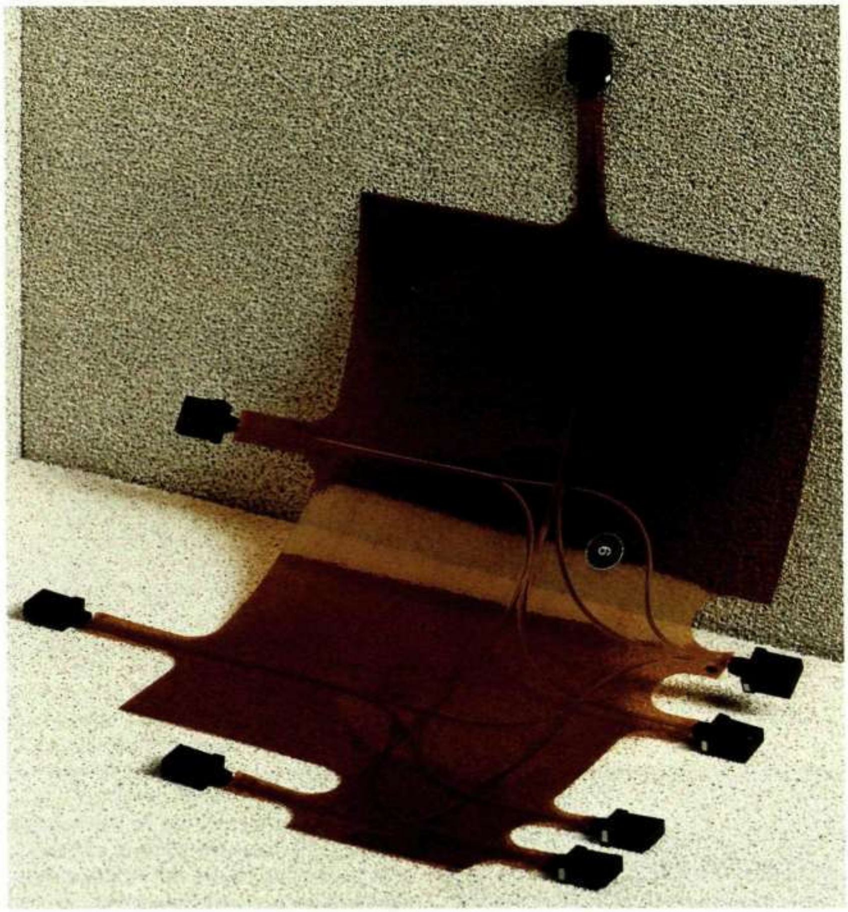


Fig. 6
Optical "flexfoil" used for fibre handling. Fibres are laminated between two sheets of a polymer material. "Tongues", cut from the foil, are terminated with MT connectors. The foils can be placed in both backplanes and PCB planes



cost since all the fibre ends are polished simultaneously.

MT connectors in the Apollo demonstrator are directly moulded on fibre using a technique developed at Ericsson. A multimode performance level is already achieved, giving the insertion loss (IL) of less than 1 dB.[4] A cost reduction of 70%, compared with the conventional mounting technique, can be obtained by applying this method to pre-fabricated cables of a predetermined length.

At present, activities involving directly moulded MT connectors aim at singlemode performance, which requires alignment tolerances less than 0.5 µm.

Special housings for MT connectors are used for backplane connection in the demonstrator.

A so-called "flexfoil", Fig. 6, is used for fibre handling in the demonstrator. Fibres are laminated between two sheets of a polymer material. "Tongues", cut from the foil, are then terminated by MT connectors, and the foils are placed both in the backplane and in the PCB planes.

The use of flexfoils has the following advantages:
- it facilitates handling of the large amount of fibre that will appear in future equipment practice
- it protects the fibre from environmental stress, human errors, etc.
- it permits three-dimensional bending and crossing of fibre, thus providing compactness and flexibility
- it has the potential for wholly-automated low-cost mass production
- its fabrication process does not interfere with the production flow for electronic PCBs with very severe temperature requirements (up to 220°C), which optical fibres, directly attached to a PCB, cannot withstand.

Opto-electrical modules
The optical equipment practice in Apollo is adapted to different types of opto-electronic modules, both developed in-house and externally sourced. Activities aimed at substantial reduction of production costs of optical modules by means of multi-functional use of polymer materials (e.g. for waveguiding and encapsulation) are briefly described in the following.

Polymer materials present an unconventional choice for telecom applications, which pose stringent requirements in terms of reliability and environmental stability.

Today more established silicon- and silica-based material are found to have good opti-

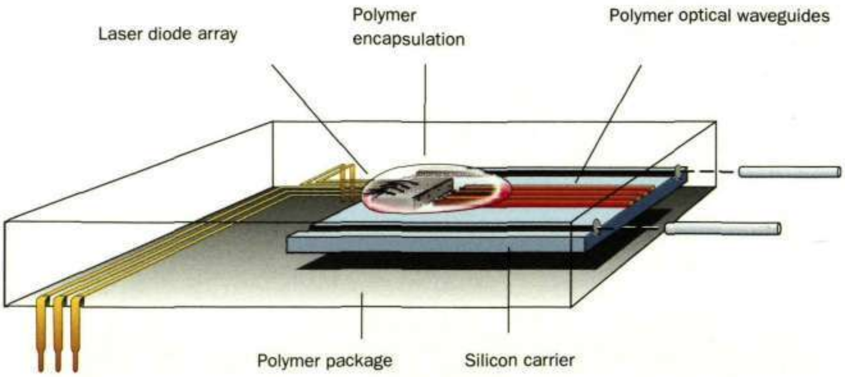


Fig. 7
Basic concept of a laser diode (LD) module, using polymer waveguides. Polymer materials are used for both encapsulation and waveguiding

Box E

Benefits of using polymer materials in optical applications:

- they have good initial qualifications in terms of mechanical, thermal, optical and electrical properties as well as material cost
- they have a potential for being "fully custom-designed" (as regards optical and electrical properties, for example) to fit a specific application
- they are production-friendly, i.e. fully developed mass production methods with only few process steps can be used, which gives very low price per unit
- they can be processed into complex shapes and with tolerances high enough to enable low-cost passive alignment and integration of different functions.

cal waveguide performance, but they do not present a low-cost alternative, since they use a complicated multi-step fabrication process. Polymer materials are production-friendly, which – together with other advantageous features, see Box E, – makes them attractive solutions for electro-optical applications.

Two different approaches to non-hermetic packaging, involving polymer materials, are investigated: one for edge-emitting light elements, such as laser diodes, LDs, and another for surface-emitting/absorbing light elements, such as PIN diodes.

One of Ericsson's solutions for an LD transmitter module, Fig. 7, incorporates waveguides, which transport light from the LD chip to the output interface of the module. In this case, polymer materials can be used for embedding the LD chip, waveguiding and encapsulation of the device.[5] Fig. 8 shows an interconnection between the LD chip and the polymeric waveguides.

These waveguides are patterned in a photolithographic process on a silicon substrate. The same technology, but other materials, has been used for fabrication of passive splitters, Fig. 9.

Multimode performance has been achieved for both active and passive devices.[6, 7, 8] Currently, activities are focused on achieving singlemode performance which is required for access applications. A promising waveguide candidate is BCB (benzocyclobuthane), but other materials are also considered.

Further cost reduction can be achieved by using polymer materials as substrates as well. A process similar to CD manufacturing – basically a combination of established materials and processes – can be applied. In this uncomplicated few-step process, the following operations can be accomplished:
- alignment of module elements to each other
- formation of waveguides, mirrors, gratings, etc.
- encapsulation of the entire device.

These techniques are studied within the Bro project (building practice research for opto- and microelectronics), Box F. Universities, research institutes and industry in Sweden work in close cooperation in order to direct academic research towards questions that are crucial to reducing the cost of opto-electrical modules.

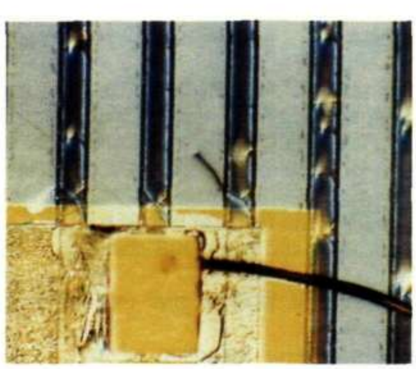


Fig. 8
The interconnection section between the LD chip and the polymeric waveguides in an LD module. The material used for the waveguides is polyimide. The whole section is covered by an optical globe top material

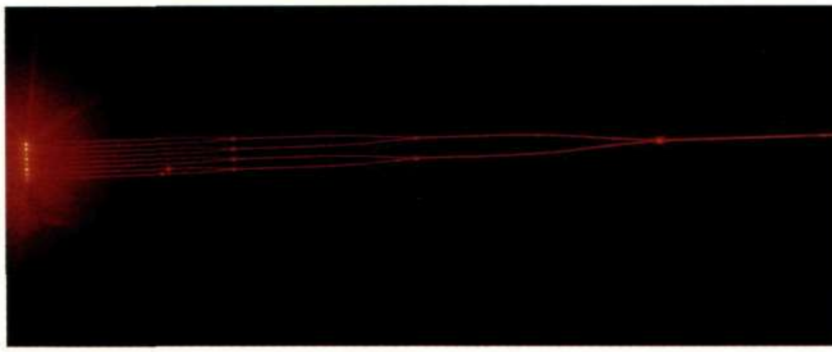
Polymer waveguides on printed circuit boards (PCB)

One PCB in the demonstrator incorporates polymer optical waveguides instead of fibre.

The incentive to use polymer optical waveguides for optical interconnects covering intra-PCB, PCB-to-backplane (BP) and intra-BP distances is that polymer waveguide technology has a potential for becoming more cost-effective in mass production than alternative glass- or polymer-fibre based technologies. Another advantage is that splitters/combiners can be introduced in the same patterning step as "straight" waveguides.

In this case, in contrast to intra-module applications, neither silicon nor ceramics represents a suitable substrate alternative. A stiff standard PCB substrate, such as FR-4 (common fire resistance standard), is a natural choice. The polymer optical waveguides can then be processed

Fig. 9
A 1:8 optical splitter with multimode performance. It is based on polymer waveguides in a new silicone material, patterned on a silicon substrate using a new photolithographic process. The average excess loss is 4.8 dB



on top of the electrical interconnect layers after sufficient planarisation of the surface.

By analogy with flexfoils for fibre handling presented earlier, an attractive alternative to a stiff board is to use a flexible polymer foil or film as the substrate for optical interconnects. The flexfoil, with a polymer waveguide pattern, can then be used as a separate optical interconnect overlayer for PCBs and BPs. It can also be laminated together with stiff PCBs and BPs, thus integrating optical and electrical interconnects.

Some important requirements, imposed on polymer materials and their fabrication processes by intra-PCB and intra-BP applications, are shown below:
- waveguide loss less than 0.1 dB/cm (desired) and less than 0.3 dB/cm (required) at a wavelength of 1300 nm for both singlemode and multimode waveguides
- cost-effective fabrication processes even for large-area (50x50 cm) waveguides, which are compatible with PCB fabrication processes, including 220°C soldering
- low-loss, low-cost and easy-to-handle connection between a polymer waveguide and a connector interface
- refractive index matched to the index of standard glass fibres
- environmental stability, long-term reliability and robustness required in telecom applications.

The "standard" process for fabrication of polymer waveguides[9], involving UV patterning of a thin polymer film via a precision mask followed by wet etching of the uncured parts, has been used. With the "right" choice of materials and process parameters, multimode buried ridge waveguides have been obtained and evaluated.

In order to obtain "large-area coverage", a new material system, which gives a "dry" surface for the lithographic step of the process, has been developed. It permits large mask to come in direct contact with the surface. Another interesting feature of the system is that it has a potential for reaching the required low optical attenua-

Box F

National co-operation project

Bro (building practice research for opto and microelectronics) sponsored by the Swedish government via NUTEK

Objectives:
development of technologies for low-cost internal optical communication links. It includes polymer waveguides, methods for passive alignment between opto-components and waveguides as well as solutions for shaping and joining semiconductor materials

Participants:
Department of Electronics at Uppsala University, Institute of Optical Research, the Institution of Energy Technology at KTH, Industrial Microelectronics Center in Stockholm and Linköping, Ericsson, Pharmacia, Toolex Alfa

Coordinator:
Kåre Gustafsson

Box G

International co-operation projects sponsored by EC's third framework for research programmes

Brite-EuRam programme: DondoMCM (Development of new dielectric and optical materials, testing and comparison with existing polymers and application in multi-chip modules)

Objectives
To develop and to investigate a new class of materials, (ormocers, organically modified cerams), i.e. "molecular mixtures" of organic and inorganic materials and to compare these with existing polymer materials in different applications, such as dielectrics for multi-chip modules, optical waveguides, optical cladding/passivation, and general non-hermetic encapsulation of circuits. Demonstrators that will prove the, hopefully, superior performance of these new materials will also be made.

Participants:
Ericsson (SE), Fraunhofer Institute for Silicate Research, FhGISC (DE), BULL (FR), Motorola (UK), Heraeus (DE), Industrial Microelectronics Centre, IMC (SE), Technical University of Berlin, TUB (DE)

Start:	July 1994
Duration:	4 years
Total cost:	4.8 MECU
Ericsson cost:	1.0 MECU,
Ericsson project manager:	Mats Robertsson

ESPRIT programme: Spiboc

Standardised packaging and interconnection for inter- and intra-board optical communication

Objectives
To negotiate a common (possibly diversified) functional standard for inter- and intra-board optical communication, applicable to both the telecom and the computer fields, thus obtaining a significantly broader base for production and to bring about (production-ready) system demonstrators for fibre-type boards and functional demonstrators for waveguide boards.

Participants:
Ericsson (SE), BNR (UK), BT (UK), BULL (FR), ETH (CH), Europtics Ltd (UK), Graseby Microsystems Ltd, GML (UK), Industrial Microelectronics Centre, IMC (S), Philips (NL), Telefonica (E), White Cross Advanced Products, WCAP (UK)

Start:	Nov 1993
Duration:	3 years
Total cost:	7.1 MECU
Ericsson cost:	1.2 MECU
Ericsson project manager:	Hjalmar Hesselbom

tion, which cannot be achieved if commercially available materials are used.

An important issue is how to interface optical modules and connectors to the waveguides. If the waveguides are attached directly to PCBs, *there is a need for both* MT-compatible edge connectors and a perpendicular outcoupling of light from the waveguides to the opto-electrical modules and components. Mirrors and micro-optic elements seem to be the preferred solution today. With the flexfoil solution, MT-compatible edge connectors could be used.

Co-operation projects

Ericsson is actively participating in two different projects, funded by the European Community (EC), in order to improve the future availability of low-cost optical interconnects, Box G.

The equipment practice in the Apollo project is part of the EC-funded Spiboc project *within the ESPRIT programme.* The Spiboc link, which is adapted for both telecom and datacom applications, has a challenging specification with 12 asynchronous channels running at 2.5 Gbit/s.

The DondoMCM project within the Brite-EuRam programme is aiming at low-cost opto-electrical modules for access applications. New types of polymers that can be used as dielectrical, waveguide and passivation materials will be developed and investigated.

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Development of AXE for New and Very Demanding Transit/Tandem Switching Applications

Kjell Sandberg and Lars Moberg

All over the world, high-capacity optical fibres and synchronous digital transmission equipment are being installed in order to rationalise rapidly growing telecommunications networks. Switching nodes that interconnect the new high-capacity transmission links must fulfil very demanding capacity requirements.

AXE responds to this situation by the introduction of two new state-of-the-art system components. A new group switch – GS-128K – more than doubles the maximum number of ports to 143,000, and a new version of the control system – APZ 212 20 – increases the call handling capacity of AXE four times.

The authors describe how these new AXE components may be used to design cost-effective, simple, flexible and powerful local and long-distance networks for the future.

In a telecommunications network, switching nodes and interconnecting links provide connection paths through the network. The location of nodes and links, and the rules for path selection (routing), define the structure, topology or architecture of the network.

Traditionally, the cost of transmission links has been considerable – and highly dependent on the distance bridged by each link. Creating short paths between end users has therefore become a matter of great importance.

For large local networks, this led to a mesh-shaped structure with many short direct routes between local exchanges. For national long-distance networks, a multi-level, hierarchical tree-structure – with mainly vertical and some horizontal links – allowed different connection paths to be kept as short as possible.

Based on these two generic structures, individual network planning takes into consideration traffic volumes, traffic interests, long-term expansion, geographical limitations, and several other factors.

However, the complexity of networks has increased to such an extent that planning, optimising and (needless to say) expanding them pose major difficulties. The main factor behind these difficulties is the rapid increase in the number of users, in traffic volumes, and in the amount and variety of equipment. This is painfully evi-

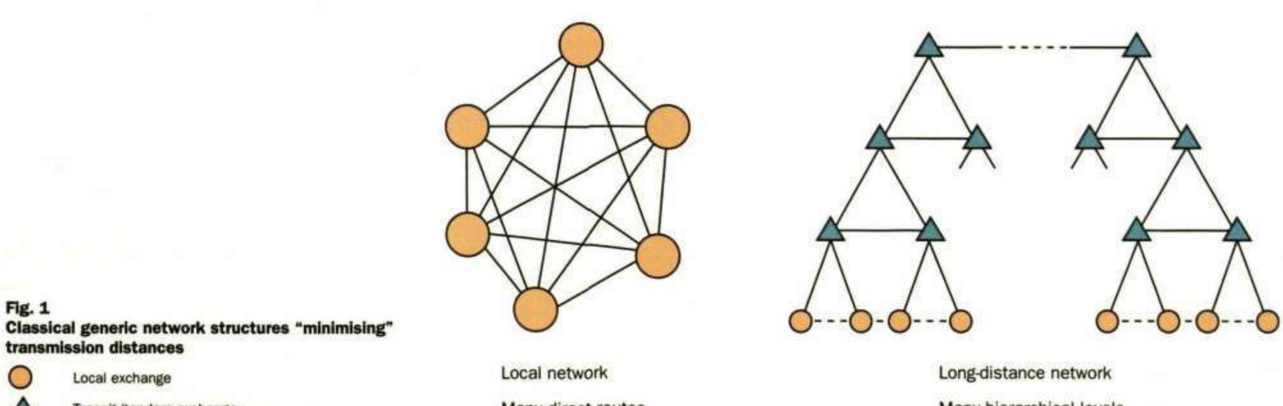


Fig. 1
Classical generic network structures "minimising" transmission distances

dent in many growing metropolitan networks, where increasing network complexity causes frequent complaints and major loss of revenues due to a poor grade of service, and where any attempts to reduce long waiting lists by installing more subscriber lines only aggravate the situation.

High-capacity optical fibre transmission systems and powerful tandem switches offer a simple and cost-effective long-term solution to this exceedingly common problem. A few powerful tandem exchanges interconnected by optical fibre can remove all congestion even in large networks, improve revenues, reduce operation costs and prepare networks for further expansion and deployment of new services. As an extreme case, all traffic may be routed in tandem (no direct routes).

Long-distance networks are simplified by removing a number of levels in the hierarchy – the network is "flattened". On the average, connection paths become longer but this causes practically no cost penalty nor any degradation of transmission quality. The new long-distance network has high and easily expandable capacity and is flexible and easy to plan, supervise and maintain.

AXE AS A TRANSIT/TANDEM SWITCHING NODE

Basic system components

Today, AXE uses a group switch with a maximum capacity of 64K ports and low internal congestion ($E_i \leq 10^{-6}$ at an average inlet load of 0.8 erlang).

Together with the APZ 212 10 control system, this group switch is used in some of the most powerful national and international transit exchanges in the world, as well as in a number of other applications for fixed and cellular telephony networks.

In response to progressively increasing loads caused by advanced signalling, comprehensive charging functions and intelligent network features, a new software-compatible version of the control system – APZ 212 20 – has been developed for general availability during 1995.

The development potential in terms of system capacity in AXE provides an opportunity to design transit/tandem nodes larger than 64K ports. In addition, there is a growing customer interest in super-large nodes that fit into new high-capacity fibre networks using synchronous digital transmission (SDH/SONET).

Considering the obvious benefits of a larger group switch – not least in terms of network development – a decision was made to add a high-capacity group switch, GS-128K, to the AXE family of system components.

GS-128K uses a new generic switch fabric concept called Uniswitch. Uniswitch is a non-blocking, fast circuit switching mechanism based on a few specially developed components that can be

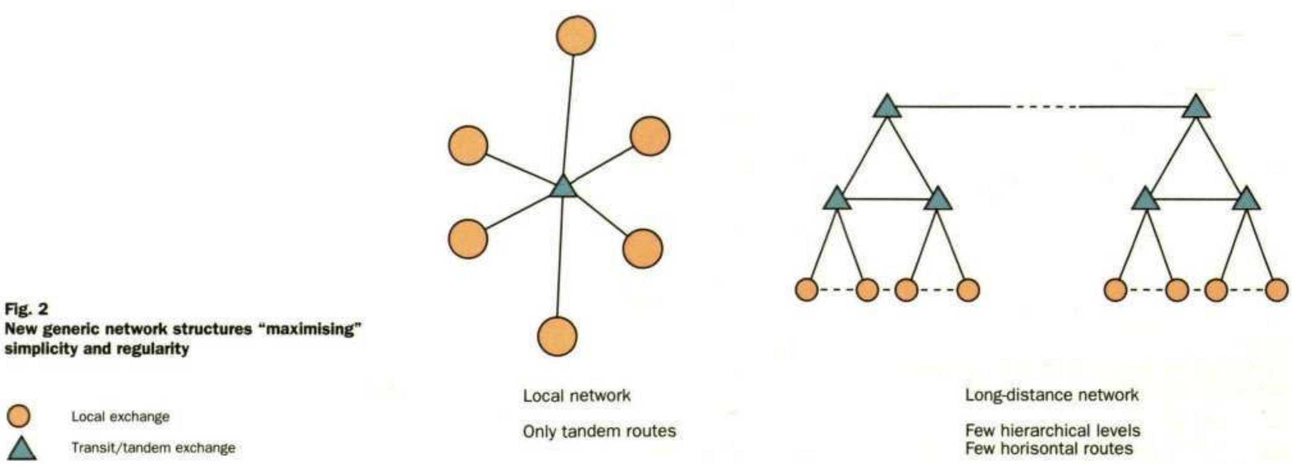


Fig. 2
New generic network structures "maximising" simplicity and regularity

Table 1

Size and traffic values for the two AXE group switches.

	GS-64K	GS-128K
Max no of ports	65,536	143,360
Max traffic per port (erlang)	0,8	1.0
Internal congestion at this traffic	10^{-6}	0
Max practical traffic per port for switched traffic (erlang)	≈0,8	≈0,8
Max total switched traffic (erlang)	≈23,600*	≈52.400**

* 10% of the ports are reserved for signalling and auxiliary devices
** 12K of the ports are reserved for signalling and auxiliary devices

arranged to provide various switch fabric sizes, e.g. 2K, 16K, 128K ports or more. The implementation of GS-128K has a final capacity of 140K ports. Approximately 128K ports are intended for carrying traffic while the remaining ports may connect signalling and auxiliary devices.

In addition to its large ultimate size, GS-128K is strictly non-blocking, which allows it to handle multi-bit-rate and semi-permanent connections without any restrictions, as well as termination of SDH/SONET transmission links.

Basic traffic considerations

The maximum capacity of GS-128K is 140K (K=1024) ports, and the maximum traffic load per port is 1.0 erlang (no internal blocking). Depending on route sizes and limitations in other network elements, the "practical" load per port varies between 0.6 and 0.8 erlang. Since some ports in the switch must be used for connection of signalling and auxiliary devices, approximately 65,000 64 kbit/s inlets are available for switching traffic to a similar number of outlets. Thus, in a practical network situation, GS-128K switches between 39,000 and 52,000 erlangs. 50,000 erlangs may be considered a reasonable upper value.

The number of call attempts per busy hour is defined by the formula $A=y \cdot t$ where

A= switched traffic in erlang
y= call intensity in BHCA
t= average occupation time per call attempt (in hours)

The occupation time for various call attempts varies considerably, depending on the type of call and the quality of the network (grade of service). It is typically c. 90 s for local calls, c. 180 s for national long-distance calls and c. 360 s for international calls. The call intensity for a node that switches 50,000 erlangs is then as follows:

- Local (tandem) calls 2 MBHCA
- National long distance calls 1 MBHCA
- International calls 0.5 MBHCA

These figures for call intensity correspond to different processor capacity figures depending on the average call complexity. The load per call is usually lower for local

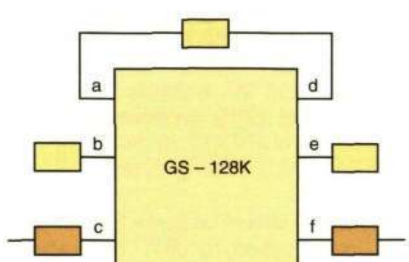
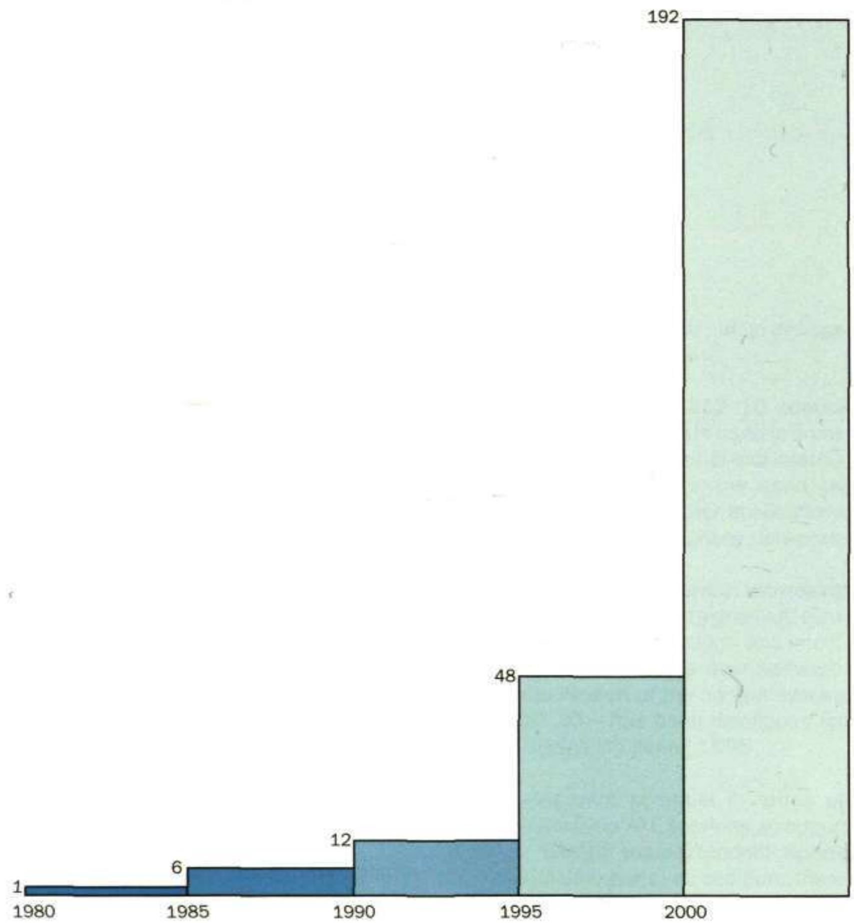


Fig. 3
Example of use of ports in GS-128K.
Incoming ports a+b+c ≤ 70K = 71,680
Outgoing ports d+e+f ≤ 70K = 71,680
Ports a+b+d+e ≤12k = 12,288 are reserved for signalling and auxiliary devices.
Ports c+f ≤ 128K = 131,072 are used for switched traffic.
Max theoretical traffic flow (leased lines) = 64K·1.0 = 65,536 erlang
Max practical traffic flow = 64K·0.8 = 65,536·0.8 = 52,429 erlang

Fig. 4
Development of control system capacity (not call handling capacity) in AXE

First AXE generation, APZ 210
Second AXE generation, APZ 212
Present AXE generation, APZ 212 10
New AXE generation, APZ 212 20
Next AXE generation



tandem calls than for national or international long-distance calls.

AXE CONTROL SYSTEM DEVELOPMENT
An AXE exchange consists of an application system, APT, with hardware switching devices and all software belonging to the application, and a data processing control system, APZ, that controls the traffic process by executing the application software.

New applications tend to become more and more complex and therefore require more and more computer capacity per call. In order to match this load increase, the capacity of the AXE control system has been increased in several steps.

The first step, from APZ 210 to APZ 212, improved the capacity six times, and the next step – from APZ 212 to APZ 212 10 – doubled that sixfold increase. A new version, APZ 212 20, which is being introduced during 1995, provides four times the capacity of APZ 212 10. Still more powerful versions are being studied.

APZ 212 20 should be perfectly adequate for large transit/tandem applications employing the new high-capacity switch, GS-128K. It is not possible to state a single specific figure for the call handling capacity of APZ 212 20 – it depends on many parameters. The APZ 212 10, however, is presently used in many customer applications, where its maximum capacity can be measured and multiplied by four to indicate the capability of APZ 212 20.

NETWORK PROTECTION
In highly rationalised networks with few but powerful nodes and links, accurate planning of the location of network elements and traffic flows is no longer a critical issue. On the other hand, protection against equipment malfunction becomes very important. Such protection must depend on the deployment of a significant amount of redundant equipment in the network and automatic transfer of traffic from faulty to functioning equipment.

The risks of major service disturbances – experienced as large signalling network outages in the United States, for example – have caused serious concern for network security in the telecommunications industry.[1] Different protection methods based on redundancy should be combined in order to minimise the risk of major service disturbances.

Table 2

Megacities

Population of metropolitan areas* in millions

City	1992	2000
Tokyo, Japan	25.8	28.0
Sao Paulo, Brazil	19.2	22.6
New York City	16.6	16.6
Mexico City, Mexico	15.3	16.2
Shanghai, PRC	14.1	17.4
Bombay, India	13.3	18.1
Los Angeles, USA	11.9	13.2
Buenos Aires, Argentine	11.8	12.8
Seoul, Rep. of Korea	11.6	13.0
Beijing, PRC	11.4	14.4
Rio de Janeiro, Brazil	11.3	12.2
Calcutta, India	11.1	12.7
Jakarta, Indonesia	10.0	13.4
Tianjin, PRC	9.8	12.5
Manila, Philippines	9.6	12.6
Cairo, Egypt	9.0	10.8
New Delhi, India	8.8	11.7
Lagos, Nigeria	8.7	13.5
Karachi, Pakistan	8.6	11.9
Bangkok, Thailand	7.6	9.9
Dacca, Bangladesh	7.4	11.5

*Urban area estimates vary widely, depending on area definitions and recency of census.
Source: Population Division of the U.N. Secretariat

A telecommunications network contains three basic levels: a physical equipment level, a transmission (path) level and a switching (circuit) level.

At the lowest level, cables and other equipment may be duplicated and geographically separated. At the transmission level, survivable ring architectures or protection switching may be used. At the switching level, general over-dimensioning of nodes and links – and the definition of several alternative paths through the network – create redundant traffic capacity. This spare capacity is dimensioned with conventional traffic calculation methods to provide acceptable grade of service in spite of equipment malfunction. It also keeps network congestion at practically zero level during normal operation.

The nodes themselves contain considerable redundancy and protection against traffic overload and equipment malfunction. The new AXE group switch has a fully triplicated switch core.

TARGET NETWORKS FOR THE NEW AXE TRANSIT/TANDEM SWITCH

The new AXE transit/tandem switch is designed to solve the most challenging network development problems into the first decades of the next century – problems that will be found in rapidly emerging megacities with a population of up to 20 million inhabitants or more, Table 2. These megacities will be important centres of industrial, commercial, social and recreational activities, and their need of various telecommunication services can be expected to be great. If we assume a penetration of 50-70 narrowband terminals per 100 inhabitants, the table indicates that megacities with over 15 million terminals would be exceptional and that most of them would have some 10 million terminals or less.

AXE MEGACITY TANDEM APPLICATOINS

A numerical example, Box A and B, provides guidelines for the application of the new AXE transit/tandem switch in future

Box A

Estimate of required tandem capacity in a metropolitan area

General assumptions for numerical calculation
Consider an area with up to several million subscribers. The subscribers are divided into n tandem areas of equal size.

The traffic model for estimating the required tandem capacity is based on the following assumptions:
- each tandem area is served by one tandem pair
- for reasons of security, all local exchanges are connected to both tandem exchanges in the pair, on a 50/50 load-sharing basis
- a limited portion of the urban traffic is assumed to be carried on high-usage routes (H-routes). This applies both to traffic between local exchanges and from the tandem exchanges to local exchanges in other tandem areas.
- urban traffic distribution proportional to the number of subscribers
- only inter-exchange urban traffic is assumed to be carried by the tandem exchanges.

Redundant capacity should be introduced in order to provide acceptable performance in case of major faults.

The figure below shows the logical network structure for the case of two tandem areas.

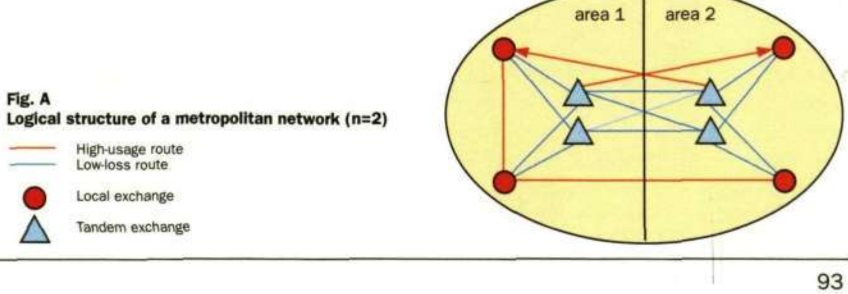


Fig. A
Logical structure of a metropolitan network (n=2)

megacity networks. This is a "worst case" example in the sense that the traffic interest from subscriber to subscriber has been assumed to be equal, i.e. traffic is distributed uniformly over the network. In reality, major traffic flows occupy routes between large local switches in city centres and can be handled without tandem routing.

Box B

Estimate of required tandem capacity in a metropolitan area

Model parameters and results

The following parameters are included in the model:

Parameter	*Denomination*	*Typical value*
Number of subscribers	N	0.4M-10M
Number of tandem areas	n	1-5
Originating traffic/subscriber	a_o	0.08 erl.
Percentage inter-exchange urban traffic of a_o	p_u	60%
Percentage of inter-exchange urban traffic carried on H-routes between local exchanges	p_{HL}	50%
Percentage of traffic from a tandem exchange to subscribers in other areas carried on H-routes to local exchanges	p_{HT}	80%
Average utilisation per port	u	80%
Traffic increase factor	f	1

f = 1 no redundancy (assumed in Fig B)
f = 2 full redundancy, i.e. no loss if one tandem goes down

The switched traffic (A_T) in each of the 2·n tandem exchanges may be expressed as
$A_T = f/2 \cdot N/n \cdot a_o \cdot p_u \cdot (1-p_{HL}) \cdot [1+(1-1/n) \cdot (1-p_{HT})]$
The required number of ports in each tandem exchange is given by $2 \cdot A_T/u$ and presented in Fig. B

Fig. B
Tandem capacity (in kports) – limited number of high-usage routes

64K 128K 256K 512K

Subscr.(M)	1 T-area	2 T-areas	3 T-areas	4 T-areas	5 T-areas
0	0	0	0	0	0
1	30	17	11	9	7
2	60	33	23	17	14
3	90	50	34	26	21
4	120	66	45	35	28
5	150	83	57	43	35
6	180	99	68	52	42
7	210	116	79	60	49
8	240	132	91	69	56
9	270	149	102	78	63
10	300	165	113	86	70
11	330	182	125	95	77
12	360	198	136	104	84
13	390	215	147	112	90
14	420	231	159	121	97
15	450	248	170	129	104
16	480	264	181	138	111
17	510	281	193	147	118
18	540	297	204	155	125
19	570	314	215	164	132
20	600	330	227	173	139

Another assumption in the example is that tandem nodes use pairs of AXE tandem switches (not necessarily geographically co-located). This means that the maximum node capacity is 2 x 128K = 256K ports. For reasons of security, local exchanges are connected to both tandem exchanges.

Fig. B shows that one AXE tandem pair is adequate for networks up to 4 million subscribers.

The subscribers are assumed to originate 320,000 erlangs. Sixty percent of this traffic, 192,000 erlangs, is assumed to be inter-exchange urban traffic. Half of it, 96,000 erlangs, may be handled by the tandem pair while the rest uses direct routes.

With the same assumptions, four AXE tandem pairs can handle networks with up to 14 million terminals.

The result of these calculations is that future megacity networks up to, say, seven million terminals could be handled by two to four AXE tandem pairs, which would also allow generous provision of redundant capacity at the switching level. A few exceptional networks in the world would require a larger number of tandem pairs.

Another – indirect – result is that there is little reason to expand the GS-128K over 140K ports.

If, however, large amounts of 2Mbit/s switched or leased line connections are required, the GS-128K group switch could be evolved and expanded to the next natural maximum size, which is 512K ports.

DYNAMIC NETWORK DEVELOPMENT

Network development with the new AXE transit/tandem switch starts with a broad idea of the structure of the future target network. A few AXE tandem exchanges (single or pairs) well below their ultimate capacity are then installed, along with their high-capacity fibre interconnection links. In the next step, traffic is moved to the tandem network in order to clear obvious bottle-necks or to prepare for removal of obsolete equipment.

From then on, traffic measurements guide the subsequent network modernisation and expansion. Changes are made according to the individual operator's own schedule and strategies, depending on his specific situation and preferences.

In some cases the fundamental issue is improve quality and reduce congestion in order to maximise call completion and service revenue. In other cases, the objective is to modernise and rationalise a reasonably well functioning network in order to reduce operation and maintenance costs.

IMPROVING CALL COMPLETION IN CONGESTED LOCAL NETWORKS

The problem of congested metropolitan networks is widely spread and well known. This problem causes considerable difficulties in network development, unless radically solved by high-capacity fibre transmission and tandem exchanges. In spite of "normal" additions of trunks and exchange equipment, the rapid growth in network size and traffic tends to perpetuate the problem.

When a network has a long waiting list of potential subscribers, the operator may feel tempted to give connection of new subscribers priority over necessary expansion of central network facilities. This strategy might easily choke the network and reduce potential revenue that is necessary for further expansion.

At ISS '84 in Florence, Angel Labandeira described a ring network implemented in Buenos Aires in 1983, the Cinturón project.[2] This project aimed to relieve network overload, which had caused an extremely low call completion ratio. Six tandem exchanges with a total capacity of some 107,000 trunks were added to the network and "the completed ratio for local calls was increased from 20 to 30% in the old network to more than 60% in the new digital network". Simultaneously, "the actual number of meter pulses [increased] approximately 29%". It is difficult to imagine another network investment with such an immediate and massive impact on revenues and probably on end-user satisfaction as well.

Serious network congestion obviously leads to a low call-completion ratio and, consequently, a substantial loss of revenue. Another effect is an increase in the number of call attempts (false traffic), which overloads all common control equipment – processors, signalling equipment, etc – in the network due to short average holding time. While the holding time for successful calls may be some 100 s, the average holding time for all calls (both successful and unsuccessful) may be down at some 35 s. When major parts of the network are overloaded it is difficult to locate the real bottle-necks, since congestion spreads backwards in the network. Moreover, it is often falsely believed that groups of common control equipment are under-dimensioned when they in fact are correctly dimensioned but for a normal call-completion ratio, i.e. normal holding time.

Opening up central paths in a heavily congested network will start a powerful benevolent circle. Revenue increases, subscriber satisfaction improves, network maintenance is reduced, unnecessary investments in common control capacity are avoided, more revenue allows more subscribers to be connected, which produces more revenue, etc.

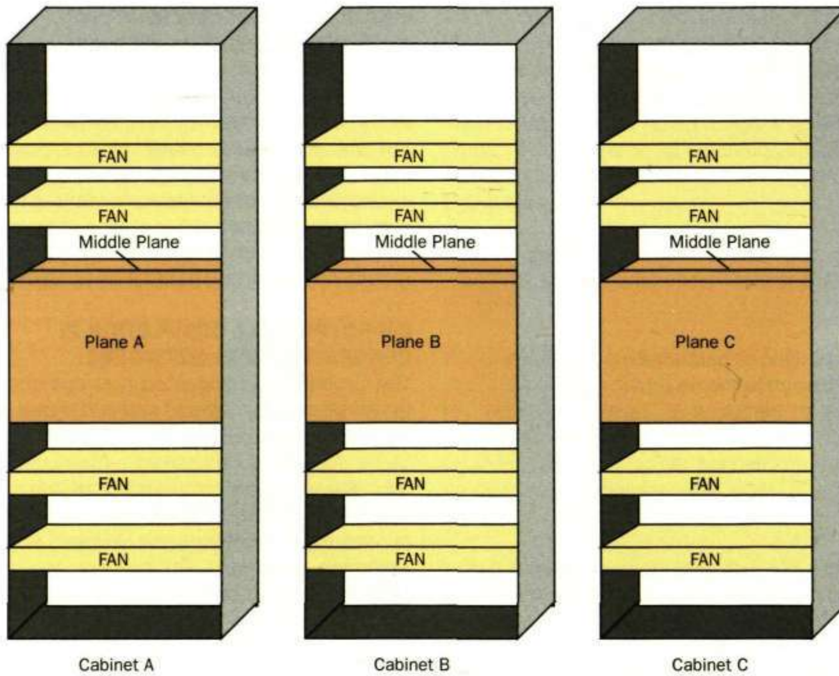
RATIONALISING WELL FUNCTIONING NETWORKS

In some instances, the network functions reasonably well in terms of call completion but is expensive to operate and maintain. The reason for this is the large number of switches and the large number of routes. If all local switches have direct routes – incoming and outgoing to all other switches – n switches will have n-1 outgoing routes and the total number of routes will be n(n-1). If all traffic is routed via tandem switches, the number of routes will be only 2n – one incoming and one outgoing route per exchange.

The tendency of the number of routes to increase as the square of the number of exchanges in the conventional mesh-shaped network structure is unfortunate. Costs and handling efforts that are proportional to the number of routes increase rapidly when the network grows.

A study of this problem (made for the development of the Stockholm metropolitan network) was reported at ISS '90 in Stockholm.[3] This study focuses on the costs of handling a mesh-shaped network compared with that of handling a tandem-based hubbed network. (Call completion was no important driving factor, since it was very high already.) The result was that "this architecture (a hub network) gives

Fig. 5
The switch core in GS-128K is triplicated with majority vote and it handles 140K 64 kb/s ports in a non-blocking T-S configuration.
It is housed in three cabinets with the dimensions W=600 mm, D=600 mm, H=2200 mm



the highest cost efficiency, the greatest simplicity and flexibility, and offers interesting possibilities of building networks with a high degree of redundancy".

TRANSIT NETWORK APPLICATIONS

The cost-effectiveness of optical fibre transmission is having a considerable impact on long-distance telecommunications as well, both national and international. Most public operators are establishing very powerful long-distance back-bone networks based on 625 Mbit/s and 2.5 Gbit/s fibre transmission with "more-than-enough" capacity in the short run. In addition, electrical power distribution companies and railway operators establish their own high-capacity optical fibre networks along their networks.

A number of submarine optical fibre cables rapidly expand the international network, and proposed submarine fibre cables encircling the coast lines of Africa and South America may provide very cost-effective alternatives to terrestrial or satellite-based international telecommunications.

Globalisation and steadily falling transmission costs will promote an increase in long-distance traffic, and some routes and switching hubs will have to be quite large. Presently, the largest AXE international switches have some 50,000 ports, which may very well be exceeded in the future.

The preferred trend for national long-distance networks is to reduce the number of levels in the network, establish districts with the same simple basic structure, irrespective of size, and establish some systematic redundancy strategy like dividing the network in two self-contained but interconnected "halves" or planes. This type of redundancy means that important nodes and routes are duplicated. Metropolitan areas may contain several interconnected long-distance nodes to provide a multitude of possible paths both for terminating and transit long-distance traffic.

BASIC CHARACTERISTICS OF GS-128K IN AXE

The main reasons for the new group switch in AXE are:

- large size to fit new network structures and to handle large amounts of n x 64 kbit/s traffic
- absence of internal blocking in order to handle n x 64 kbit/s connections without limitation, as well as semi-permanent connections
- a compact switch core
- a new switching technology that allows future expansion above 140K ports.

GS-128K is based on the new Uniswitch fast circuit switch concept, which has a simple, non-blocking time-space (T-S) structure that could be evolved and expanded in the future.

The switch matrix is implemented in one cabinet per plane for 140K paths – there are three cabinets in total due to triplication, Fig. 5.

While the present AXE group switch is almost non-blocking (internal congestion $\leq 10^{-6}$ at an average inlet load of 0.8 erlang), the GS-128K is strictly non-blocking in order to provide switched and semipermanent wideband connections without any pre-engineering or other limitation. Being non-blocking, the group switch may also provide integrated digital cross-connect functionality at the 1/0 level.

The main characteristics of GS-128K are listed below:

- Maximum size 140K ports
- Non-blocking
- Traffic per port $\leq$1.0 erlang
- n x 64 kbit/s paths with preserved Time Slot Sequence Integrity, semi-permanent and on demand (switched).
- Prepared for termination of SDH/SONET
- Switch matrix triplicated with majority vote
- MTBSF > 1000 years

SWITCHING FUNCTIONS IN AXE

AXE provides a vast and growing number of functions and features and signalling systems for a broad range of switching applications. Although this article focuses on the capability of AXE to provide cost-effective network structures that streamline traffic flows and increase revenue, AXE can also be used to introduce new functionality into the network.

The main product line for AXE transit exchanges was described in Ericsson Review 4:1992.[4] On-going development includes additional functionality for a number of important future-oriented application areas: international switches, intelligent networks, operator services, charging, mobility in the fixed network, etc.

GATEWAY FUNCTIONS IN NATIONAL LONG DISTANCE NETWORKS

Telecommunications operation is rapidly being liberalised in many countries in the world. As a result, national public telecom operators will have to – or choose to – interwork with many other operators. This means that international gateway functions, like signal translation, inter-administrative accounting, etc, will no longer be needed only at national boundaries but in principle anywhere in a country where links are established between different networks or operators.

In other cases, e.g. for International Virtual Private Networks, functionality that used to be national and controlled by one operator will be extended over national boundaries and will need to be harmonised between different operators.

Gateway functions were integrated into AXE applications for international switching a long time ago, and they will become particularly valuable in future national transit networks operating under new regulation.

ROLL-OUT OF GS-128K

GS-128K is a complement to the present 64K GSS in AXE, not a replacement. The switching capability of GSS is perfectly adequate for all present circuit-switched long-distance and metropolitan networks in the world. Fig. B indicates that the 64K GSS easily provides relief to multi-million metropolitan networks.

In the Attica Ring project in Athens, six AXE tandem exchanges – each with 35,000 ports – provide a tandem backbone network serving approximately 2 million subscribers connected to 177 local exchanges installed at 70 sites. In Sweden, AXE with GSS is employed in a radical all-network modernisation and rationalisation program that will be completed in 1997.

GS-128K, which will be introduced in 1997, will satisfy entirely new network requirements that may or may not materialise around the turn of the century: extensive use of 2Mbit/s switching, super-size switches for exceptional networks, direct connection and adaptation to SDH/SONET fibre transmission links, etc.

When GS-128K is introduced in 1997, the functional content – i.e. the application software – will be identical for AXE transit/tandem applications, irrespective of which of the two group switches is used.

SUMMARY

The rapid improvement of optical fibre transmission creates a strong economic incentive to concentrate traffic in few high-capacity routes wherever this is possible. Together with high-capacity switches, new network structures can be built, combining vast amounts of traffic with simplicity, flexibility and cost-effectiveness.

A new group switch for AXE – GS-128K – with a maximum capacity of 140K 64 kbit/s ports is being developed for such applications. A numerical example demonstrates that a few powerful tandem nodes – paired for size and/or redundancy – are capable of meeting the circuit switching demands of the largest metropolitan networks foreseen for several decades.

In addition to being a vehicle for extraordinary traffic flows in fibre-based networks, AXE may also provide advanced additional functionality to many networks in the world.

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