GEC REVIEW

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GEC REVIEW

incorporating *THE GEC JOURNAL OF TECHNOLOGY*

Editorial

Welcome to the first issue of GEC Review, incorporating The GEC Journal of Technology. After fifteen years of publishing companion journals with different, distinct focuses, we have decided to consolidate our efforts into a single entity – to remain known as GEC Review. We therefore intend that this should contain papers from throughout GEC, presenting all aspects of the Company's technology from research through to products, just as the first 'GEC Journal' did in 1930, under the auspices of Sir Hugo (later Lord) Hirst. We shall, of course, reach a much wider audience than was the case seventy years ago because of our parallel publication route via the world wide web.

Readers with a keen interest in colour and design may be interested to know that our new front cover is now printed using the PANTONE® Hexachrome® ink system. Hexachrome is a six-colour printing process that yields a significant improvement in colour range (gamut) over the conventional four-colour system. The special set of pure inks comprises modified cyan, magenta, yellow and black, with the addition of vivid orange and green. The use of these inks enables the production of eye-catching designs with impact. We believe that the use of such a state-of-the-art ink system thoroughly befits our 'new' journal.

A. J. Walkden

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The Photonics Future

Unique developments by Marconi Communications deliver all the bandwidth-enhancing benefits of photonics technology to national and even metropolitan networks. This paper describes these developments – notably the world's first Reconfigurable Optical Add/Drop Multiplexer, providing ability to add and drop wavelengths in a fully-managed system. It illustrates how they augment existing wavelength division multiplexing (WDM) technology and assesses their overall market significance.

Keywords: photonics; communications; bandwidth; wavelength division multiplexing; WDM; dense wavelength division multiplexing; DWDM; optical routeing; Reconfigurable Optical Add/Drop Multiplexer.

CAMERON, A. A.

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Integrated Night Vision in Helmet-Mounted Displays

Night Vision Goggles (NVGs) are a primary means of providing enhanced vision at night for many rotary-wing and fixed-wing aircraft. The drive to introduce Helmet-Mounted Displays (HMDs) into service has resulted in the desire to combine the function of the Night Vision Goggle with that of the HMD. This paper provides an overview of NVG technology and addresses the requirements and design issues surrounding integrated NVG and display systems. Several practical implementations are discussed that are either in service or are due to enter service shortly. The paper covers both the rotary-wing and fast-jet requirements and discusses the differing operational needs, and how these impact the practical implementation of integrated helmet systems in each case.

Keywords: night vision; Night Vision Goggle; NVG; visor projected; Helmet-Mounted Display; HMD; helmet-mounted sight; helmet tracker.

MASELLA, E.

GEC REVIEW
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Achieving 20cm Positioning Accuracy in Real Time Using GPS, the Global Positioning System

Real-time kinematic carrier-phase differential GPS, or more commonly referred to as RTK, is becoming indispensable for an increasing number of applications requiring centimetre-level positioning accuracy. In order to respond to this demand and to offer this accuracy to a broader range of users with stringent price requirements, a cost-efficient solution is required. Canadian Marconi Company (CMC) has recently developed an RTK GPS engine called the RT•Star, a low-cost single-frequency RTK-capable sensor that can obtain nominal accuracies of 20cm or better under any given dynamics. The sensor is user-configurable, either as a reference station or a roving unit. This product is considered to possess one of the highest accuracy-over-price ratios in the OEM sensor industry and is targeted mainly at precision agriculture, control, and Geographical Information Systems (GIS) applications. The receiver's architecture and specifications are presented in this paper, along with supporting simulation data and test results.

Keywords: Global Positioning System; GPS; differential GPS; Real-Time Kinematic; RTK; GPS receiver; Kalman filter; reference station.

BUCKLE, D. F.

GEC REVIEW
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The SIMTEC Simulation Framework

SIMTEC is both a large model with a wide range of applications and an initiative in software re-use (that is, a 'framework'). It has the modelling functionality to simulate an arbitrary combination of air, land or sea scenarios involving the interactions of several platforms, each of which can be simulated at a variety of fidelity levels, and is capable of making its decisions and of participating in C3I (Command, Control, Communication and Information) hierarchies. The modelling functionality is supported by a powerful User Environment, which is automatically configured to the modelling code and thus completely generic. Software re-use is obtained by using an object oriented library approach which is disciplined by plug-and-play interfaces and constructed in a fashion that permits unprecedented data configurability by the user and involves both using and producing COTS/generic solutions. The SIMTEC framework is shown to be complementary to other initiatives such as DIS (distributed interactive simulation) and HLA (high-level architecture).

Keywords: simulation; modelling; frameworks; software re-use; HLA; DIS; C++; object orientation.

TYLER, S. G. and YOUNG, T. P.

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Packaging, Interconnect and the Systems Integrator

New trends in packaging are explored in order to determine their strategic impact on system integration. Traditionally-cited benefits include increased functionality and reduced cost, weight and power consumption. Ultimately these may be overtaken by other factors such as the ability to integrate a wider set of functions into the interconnect fabric, the impact of this fabric on system partitioning, and the emergence of novel strategies to combat obsolescence. This paper describes several strategically-important aspects of the packaging scene and draws some conclusions about the position of such R&D in the systems community.

Keywords: electronic packaging; interconnect; multi-chip modules (MCM); printed circuit boards (PCB).

HIRST, H.

GEC REVIEW
Vol.14(1), 1999, 47

The History of the General Electric Company up to 1900 – Part 1

During 1920, Hugo Hirst gave a series of lectures to the GEC Debating Society, of which he was Chairman at that time. During these talks he described the events that took place during the five years leading up to the formation of the General Electric Company in 1886, through to the year 1900. These lectures were recorded in shorthand and subsequently transcribed into typescript. The final version, with annotation by Hirst himself, now resides in the GEC Archive collection. In this paper, which is divided between successive issues of GEC Review, we present selected extracts from these lectures, some 100 years after the events which he described took place.

Keywords: The General Electric Apparatus Company; Hirst; Byng; carbon arc; catalogue; Everything Electrical; lamps; cables; glassware.

The Photonics Future

by P. GRIFFIN, B.Sc., M.Sc., M.I.E.E., C.Eng.,
Marconi Communications

Phil Griffin graduated with a B.Sc. in Electrical and Electronic Engineering and an M.Sc. in Digital Communications Systems and Electronics. He joined the Plessey Company in 1977 and became an Engineering Project Manager for their Optical Multiplexer product range before joining GPT. He was involved in SDH from its very earliest days as a feasibility project in 1988. He was SMAI Product Champion from 1991 to 1994, SDH Engineering Development Manager from 1995 to 1997, and SDH Development Director, GPT from January to August 1998. Upon the formation of Marconi Communications, he was appointed Photonics Development Director. Phil is a Chartered Engineer.
(E-mail: phil.griffin@marconicomms.com)

Unique developments by Marconi Communications deliver all the bandwidth-enhancing benefits of photonics technology to national and even metropolitan networks. This paper describes these developments – notably the world's first Reconfigurable Optical Add/Drop Multiplexer, providing ability to add and drop wavelengths in a fully-managed system. It illustrates how they augment existing wavelength division multiplexing (WDM) technology and assesses their overall market significance.

Bandwidth Bottle-necks

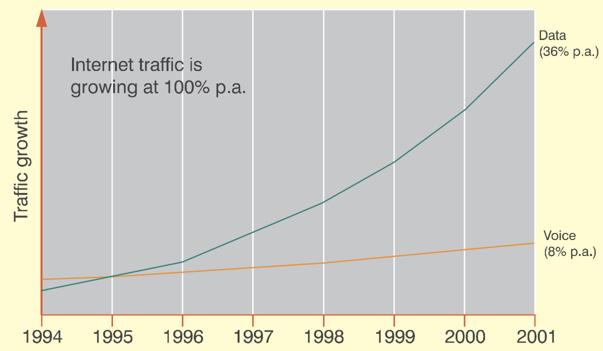
Demand for bandwidth is growing at a phenomenal rate – some commentators put data volumes expanding by as much as 36% per year (fig. 1). While attention tends to be focused on end-user connectivity, it is in the core or backbone – particularly in public networks – that congestion is the bigger threat and already becoming apparent.

To meet capacity demands, telecommunications carriers world-wide are investing heavily in upgrading their core networks, such as Cable & Wireless Communications' Network 2000 project and an £800 million investment by BT in core infrastructure.

They have three choices:

- Install more fibre, which is expensive for new entrants leasing fibres from third parties and even for existing PTOs (Public Telecommunication Operators) with established ducts. The cost of installing just 1km of fibre ranges from around £25000 to £75000; an operator with existing rights of way, such as waterways or electricity pylons, can expect to pay several thousand pounds per kilometre.
- Migrate to STM-64 (10Gbps) transmission capability in the core network which, in many cases, involves expensive upgrade of the cabling and deployment of new equipment.
- Adopt wavelength division multiplexing (WDM) technology, which delivers more capacity quickly and, by comparison with the other choices, more economically.

The use of optical fibre – developed for telecommunications transmission from the early 1980s –



1 ***Data are driving future traffic growth (source: Frost & Sullivan)***

together with the science relating it to wavelength multiplexing, switching and amplification – which has become known as 'photonics' – hold the key to solving this capacity challenge.

The maximum transmission speed has been revised upwards many times in recent years, as much as four-fold at each step, with the steps getting ever closer in time. Since the early 1990s, the established Plesiochronous Digital Hierarchy (PDH) transmission network is being rapidly replaced by the Synchronous Digital Hierarchy (SDH) and its US equivalent, the Synchronous Optical NETwork (SONET).

The International Telecommunications Union (ITU) defines basic transmission rates within SDH. The highest today is 10Gigabits per second (Gbps) per fibre, with further levels defined – though not fully specified. Some long-haul trunk players adopting WDM technology are examining up to 40 wavelengths, each capable of carrying 2.5Gbps, down a single fibre.

Today, most operators have only 2.5Gbps systems installed in their core network and, despite this seemingly enormous backbone network capacity, fibre congestion is already a significant problem for some carriers.

SDH and the ability to switch and route data around the world through SDH-based digital cross-connects have provided a solid foundation for carrier networks. However, it is rapidly reaching capacity limits using conventional electronic switching mechanisms. It is WDM and succeeding developments, such as those outlined below, that will provide the response to this challenge.

WDM and DWDM

WDM is not a new idea – it has been demonstrated in laboratories for years – but it is only now becoming economically feasible to implement WDM commercially. In essence, WDM splits the single laser-generated lightwave carried by an optical fibre into several wavelengths, each amounting, in effect, to an individual 'colour' of the spectrum and each carrying a high-capacity information channel – voice, data and video in digital form – each one equivalent to that of the original whole fibre.

Through a combination of filtering and multiplexing – dividing and concatenating the numerous signals as appropriate – the system transmits more channels, more efficiently over the same piece of fibre. WDM also sidesteps problems such as signal dispersion manifest in earlier technologies at high transmission speeds by providing higher capacity at lower speeds, without the need to increase the individual transmission speed.

A further development is the emergence of Dense WDM (DWDM), enabling many more optical signals per fibre. 'Dense' refers to the ability to support eight or more different wavelengths – up to 16 in systems commercially-available today with 32-channel density available shortly. The total bandwidth supported by a single fibre in traditional systems can now be multiplied by the number of channels or 'carriers'.

DWDM over long distances is made possible by amplifying the optical signal – a technique first used for submarine cables then applied to terrestrial networks where geographic barriers, such as swamps or mountains, prevented the network operator from installing conventional equipment to regenerate the signal. In DWDM the optical amplifiers amplify the multiple wavelengths; as the amplification is shared across all channels, far fewer amplifiers are needed.

It is no exaggeration to suggest that within the next few years, a single optical fibre enhanced by WDM will one day transport 25 terabits of data per second. Today, one day's entire data traffic carried in the US amounts to less than one terabit.

Not only is the transmission capacity of backbone networks increased but, by re-using existing infrastructure, telecommunications companies avoid the spiralling cost involved in laying new cable.

The first carrier to adopt DWDM for mass deployment was Sprint Long Distance in the US, heralding adoption of DWDM by many other long-distance operators in the US and, more recently, in Europe. Other examples of WDM and DWDM in action include the 30,000km-plus global undersea cabling project SEA–ME–WE 3 (South-East Asia–Middle East–Western Europe) and WorldCom's pan-European optical fibre network.

Since becoming available in 1996, DWDM equipment sales have sky-rocketed, with projections of over $3 billion annual sales in North America by the year 2000 and a further $1.5 billion across the rest of the world.

Moreover, WDM is the pre-cursor to all-optical networking, where the constraints of the traditional electronic domain no longer apply. An all-optical network has the potential to transport, route and deliver even greater amounts of bandwidth more cheaply than electro-optical solutions.

From Long- to Short-haul

Until now, commercially-available WDM systems, such as those from Marconi Communications, have been focused on point-to-point installations. Although optical amplifiers can extend the range and the signals can be regenerated, they have remained essentially systems carrying light waves from A to B, invariably in the long-haul backbone market for organizations such as WorldCom and Sprint and pioneered as operational systems in the US.

WDM is now mainstream technology in this market, fuelled by the tremendous benefits it delivers as an alternative to laying new fibre (see box on following page). And, importantly, the business drivers are accentuated the closer one gets to the points of access to the network. WDM is now being considered at the national, regional and even intra-city levels.

SDH provides a precedent: it began in long-distance networks. The turning point was the emergence of ADMs (Add/Drop Multiplexers), enabling fibres to be added or removed at particular nodes in the network as the capacity needs dictate. The regional layer or lower levels of a backbone network demands, moving gradually towards the access layer, demand this flexibility.

Marconi Communications is the first to develop the ability to add/drop at the optical layer, so enabling WDM systems to be introduced into the

The Advantages of WDM/DWDM

- Multiple services available independently on a single fibre, such as ATM and frame relay.
- Saving on the provision of fibre cables and ducts.
- Saving on transmission equipment, such as optical amplifiers and signal regenerators.
- Less capacity is needed in the SDH cross-connects.
- Shorter lead time to add new capacity compared with installing new fibre.
- Ability to provide network resilience by freeing up previously full cable routes.
- Greater flexibility in network planning.
- WDM is not constrained by a lack of standards – fibre is adopted as a global medium and carries simultaneous streams of information in their native format, such as ATM or IP, without the need to package or encapsulate them independently of each other,

network nearer the access points – in other words, closer geographically to the end users – with all the advantages of optical, rather than electromagnetic transmission.

The target for the new type of device is the inter- or perhaps intra-city hop up to about 100km span between nodes. WDM products have, to date, been too expensive to consider at this level of network granularity.

The primary focus is likely to be financial centres – notably London's Square Mile – in which numerous financial institutions need the highest 'Quality of Service' guarantees from their service providers, speed of installation, comprehensive management and unprecedented service flexibility. Of course, such areas are also the most expensive in which to lay new fibre.

All-optical Routeing

Marconi Communications' new PMA-8† is the world's first reconfigurable optical Add/Drop Multiplexer. Available commercially from early 1999, it enables services to be delivered at the optical level over a fully-managed and fully-resilient fibre ring. Rings with a PMA at each site linking, for example, numerous metropolitan locations such as a financial district, can be built on SDH principles but with the additional advantages of WDM, providing access from each node and elsewhere.

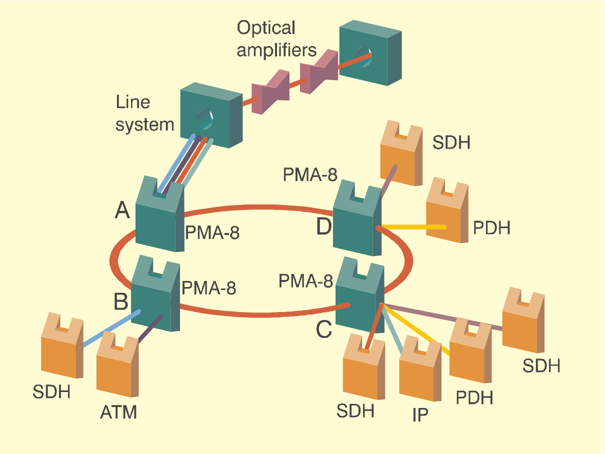
Traffic passes through a fibre as an optical signal between two points. To switch traffic through a conventional SDH ADM, it must be reconstituted as an electrical signal as it reaches the destination SDH node. To route A to B to C to D using conventional technology, information resides in the electrical domain at A. A laser is shone down the fibre, carrying the data in the optical domain to reach B where it is converted to electronic signals by the SDH ADM at B. A data stream intended for C must then be carried by another laser beam in the optical domain through to the ADM at C, where it is once again reconverted to electric impulses. The same conversion process is again necessary to reach D.

This is as complex and expensive as it sounds, whereas having a Marconi Communications PMA at each node enables the service provider to keep the data stream entirely within the optical domain on its journey around the ring.

Should C, for instance, move to a new location or wants to drop out of the network ring, no fibre re-routeing is necessary. Connection and configuration changes to the 'virtual' fibre connection can be implemented remotely at the WDM layer from a central management location, controlling an optical switch. This delivers unprecedented cost and flexibility benefits in a fast-moving and often uncertain market.

Service Flexibility

Fig. 2 presents an eight wavelength core passing by a metropolitan area fibre ring. Four wavelengths are to be dropped off and sent around the ring. Installing a PMA at each node, A, B, C, D in the example, enables each site to take off only those services it needs from the ring and add



2 ***Service flexibility***

† PMA = Photonic Multiplexer Access

The Benefits of PMA

- Less investment in network equipment including switches and amplifiers.
- Fully-configurable, including remote configuration.
- Unprecedented network flexibility.
- Fully manageable via existing management systems.
- Enables information to be carried at the optical layer in its native form, rather than encapsulated in SDH containers.
- The network enjoys all the fault-tolerant features associated with SDH rings.

on, for onward transmission, whatever services it chooses. Only SDH equipment relating to those active services is necessary at each node.

Conventional technology demands that to extend the network from the core into the ring, all eight wavelengths – each with its own SDH ADM – would have to be installed. Using a PMA at the drop-off point in the trunk means that although one SDH ADM is still needed for each wavelength, only four SDH ADMs are needed as, in this example, only four wavelengths are going to be passed around the metropolitan ring.

This has several benefits: less investment in equipment is needed; there are fewer points of failure and far less fibre – often a rare commodity at this level of the network – is needed. Information remains in the optical domain as it passes from the trunk to node A in the ring and onwards. In the example, services and capacity on only two wavelengths may be needed at B, so a PMA carries the remaining two optical signals onwards around the ring towards C, amplifying them without having to regenerate them.

At C, in our example, two additional wavelengths are added to the two coming from B. This involves only enough active SDH equipment to receive the capacity needed at that particular site and to generate the new wavelengths from that point in the ring. The fibre has the capacity to carry up to eight wavelengths, giving tremendous flexibility to each node – the equivalent of one or more end-user organization sites – taking services from the telecommunications operator.

This can be contrasted with current technology: eight SDH ADMs would be needed at *each* node to deliver the equivalent service from the eight-wavelength trunk. Marconi Communications' Smartphotonix family of devices amplifies and passes any signals that are simply traversing a node, retaining that data entirely in the optical domain.

For customers with an existing ATM switch with optical capabilities – able to take a fibre directly into the back of the device – there is no need for investment in SDH equipment at the node, just in one PMA that is needed to manipulate the incoming and outgoing optical signals (fig. 3).

In addition, each wavelength carries a discrete service – in theory, up to eight services could enter a node and eight completely different ones could exit back into the ring.

A Fully-managed and Resilient System

Not only can a PMA installation be reconfigured remotely as the operator's customers' business needs dictate, Marconi Communications' photonic rings are fully manageable with the same look and feel as existing Marconi Communications' SDH management systems.

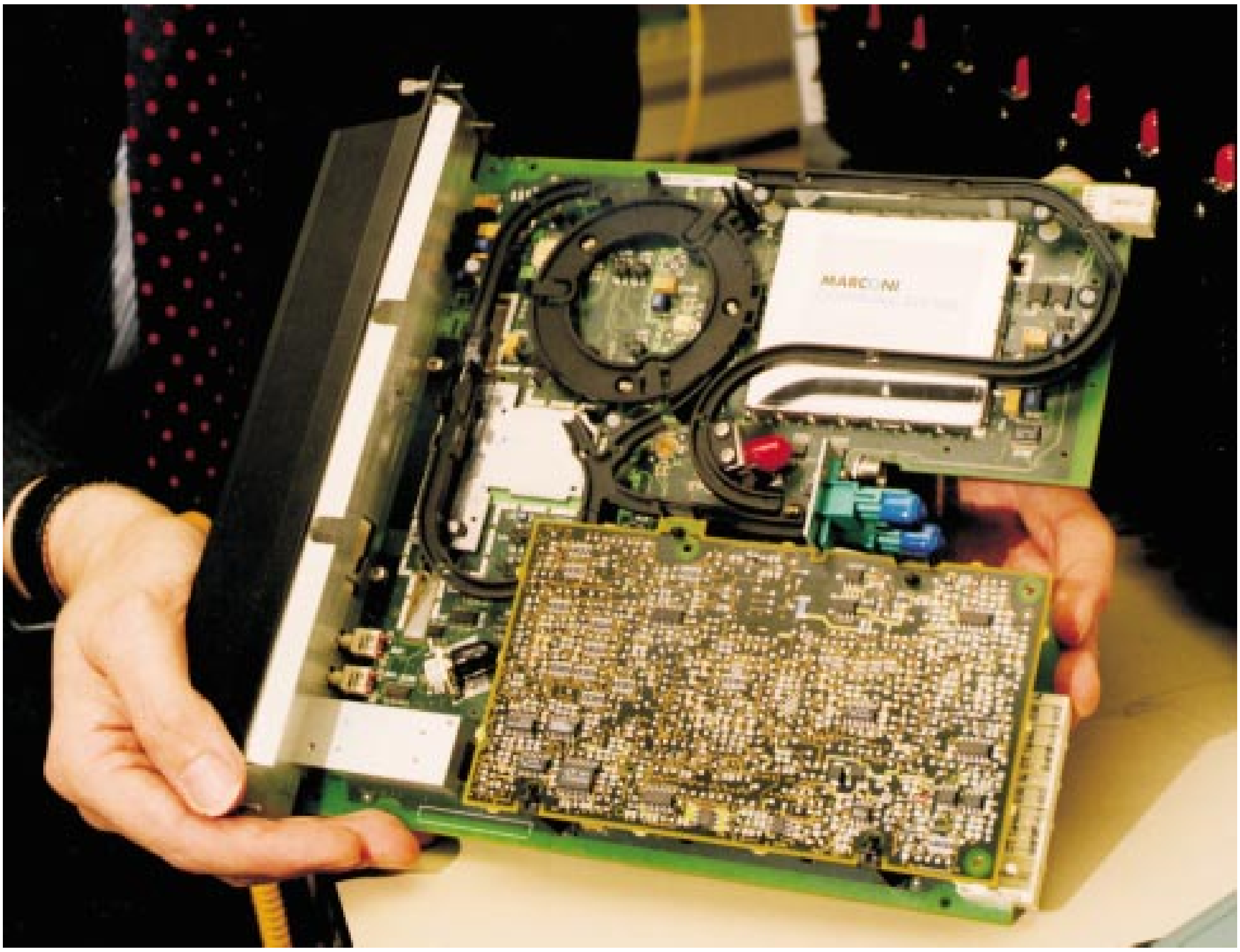
Until now, transmission technologies such as ATM and IP have always had to be packaged into SDH to ensure they have the benefit of SDH's inherent protection mechanisms. In their native form, such resilience – essential in the business-critical environments in which SDH thrives – does not exist.

With the advent of the PMA, these carrier-grade protection mechanisms become available for all types of transmission protocols, operating at the optical layer. Native IP or ATM information, for instance, can be sent in both directions around the ring, providing protection in the event of failure: information is immediately sent in the opposite direction to the problem link or node.

Future Direction

Future WDM implementations will scale upwards from 2.5Gbps per wavelength in an eight-wavelength system to, most likely, 10Gbps in the first instance. Whereas, in our example, each node has in theory a data-handling capacity of up to 40Gbps data (8 × 2.5Gbps incoming and the same outgoing), in future this could exceed 80Gbps.

Not only will the world market for this far more flexible form of WDM, based around PMAs, be huge, it is also likely to exceed estimates, rather as bandwidth volume predictions have been outstripped by demand.



3 ***The SmartPhotonix multiplexer***

These innovations in carrier-grade information transport have been developed by Marconi Communications' world-leading engineering group based in Beeston, near Nottingham. In the past, Beeston has produced the world's largest ASIC (Application-Specific Integrated Circuit), for example, for an SDH switch.

Work continues in order to develop fibre components and methods of using fibre to new levels of efficiency and flexibility, such as reducing the amount of fibre – and expensive and time-consuming fibre terminations – needed within, and to connect, network devices. More devices than ever can be placed on a single silicon substrate. Marconi Communications engineers have also enhanced the design of its switches to make the PMA as near plug 'n' play as possible – far in advance of anything else commercially available. For example, the use of an optical backplane reduces the 'spaghetti' of fibres associated with WDM terminations. It also protects the fibre connections by separating them from the electrical backplane and provides a standard card for a range of devices, including switches and line interfaces.

Much of the new WDM technology has been developed from work on fighter aircraft, where performance, fault-tolerance, size and ease of maintenance are critical. It heralds an era in which information is processed increasingly in the optical domain and light can be 'processed' as easily as electrical signals. Through developments in transmission and physical component design, much of the complexity can be isolated, so that the telecommunications operator can concentrate on operational and revenue-generating issues rather than the underlying delivery mechanisms.

Marconi Communications staff at the Beeston laboratories continue to push back the boundaries of what is possible and commercially feasible with photonics technology for the world's service providers.

Integrated Night Vision in Helmet-mounted Displays

by A. A. CAMERON, B.Sc.
Marconi Avionics

Alec Cameron graduated from Strathclyde University in 1978 and joined GEC Avionics, working in the Flight Automation Research Laboratory on advanced experimental display systems. Later he was given responsibility for the laboratory's experimental viewing systems activities, looking after various stereo viewing and helmet-mounted display projects. In 1987 he moved to the Airborne Displays Division on the 'Cat's Eyes' Night Vision Goggles Programme, taking it to the pre-production phase before joining the displays design group in 1988 with responsibility for design activities on various advanced displays projects, but with special responsibility on helmet-mounted systems. Later he became one of the founder members of the Helmet-Mounted Displays group with involvement in the development of all aspects of HMD and NVG technology. Subsequently he led the development of the Head Tracker systems, and HMD display drive electronics, with involvement in all advanced HMD systems within GEC Avionics. His current role is Chief System Engineer for the Marconi Avionics Airborne Displays Directorate (HMD). (E-mail: alec.cameron@gecm.com)

The primary function of the aircrew helmet is to protect the pilot. The advent of night vision devices and helmet mounted displays places additional constraints on the helmet, which is now an important element of the cockpit displays system, providing weapon aiming, and other information – such as aircraft attitude and status – to the pilot. The development of helmet-mounted displays (HMDs) for the military cockpit environment is therefore a demanding task if the operational benefits are to be realized without affecting pilot safety.

Night vision goggles (NVGs) are a primary means of providing enhanced vision at night for many rotary wing and fixed wing aircraft. The drive to introduce integrated helmet-mounted displays into service has resulted in the desire to combine the function of the NVG with that of the HMD.

In many applications this is achieved by adapting current in-service NVGs with the addition of a display device, such as a miniature cathode ray tube (CRT), to provide a display of symbology superimposed upon the night scene seen through the goggle.

Several integrated day/night helmet-mounted displays have been developed that provide additional capabilities, and also overcome some of the limitations inherent in the NVG-based solution. Many of these designs use the helmet visor as the display surface, whilst some utilize combiner eyepieces in front of the pilot's eyes. These systems provide wide field-of-view (FOV) displays that can be used in both day and night applications and include night vision sensors to provide the user with an enhanced view of the night scene.

Glossary

ANVIS	aviation night vision
CRT	cathode ray tube
FLIR	forward-looking infra-red
FOV	field of view
HMD	helmet-mounted device
HMDS	helmet-mounted display system
HUD	head-up display
IIT	image intensifier tube
NVG	night vision goggle
TI	thermal imager

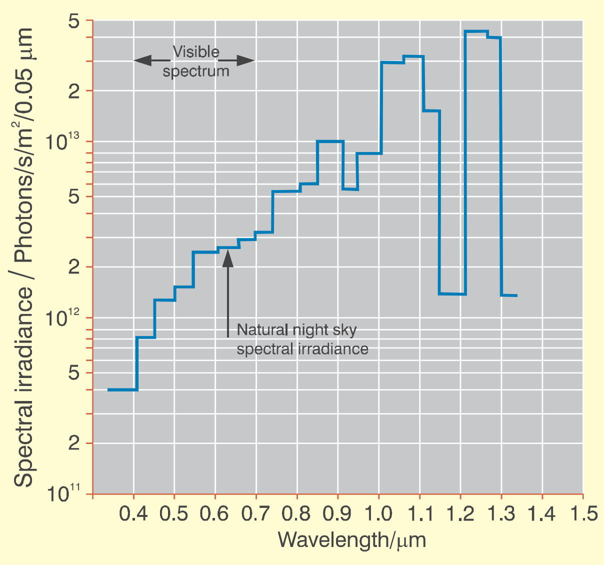
Night Vision Goggles

Principle of Operation

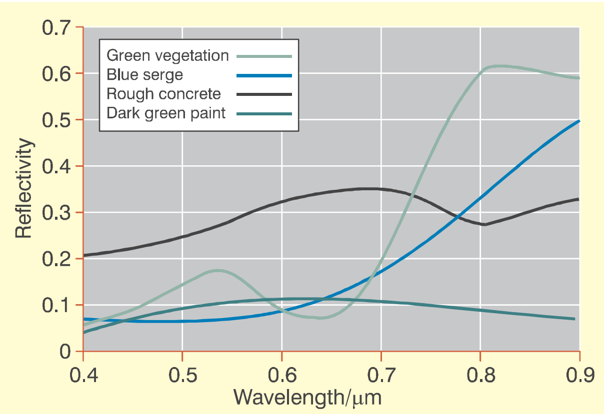
Night vision goggles use available red and infra-red (IR) light from sources such as the stars, moon and the night sky, intensified sufficiently to be presented to the eye as a visible image. All night vision goggles operate on the same basic principle and use image intensifier tubes (IIT) to produce a bright monochromatic (typically green) electro-optical image of the outside world in light conditions where the unaided eye can see little or nothing.

The human visual perception system is optimized to operate in daytime illumination conditions. The visual spectrum extends from about 420nm to 700nm and the region of greatest sensitivity is near the peak wavelength of sunlight at around 550nm.

However, at night, far fewer visible light photons are available and only large, high-contrast objects are normally visible. Fine-detail and low-contrast objects are not resolvable by the human eye; its photoreceptors (rods and cones) must receive large numbers of visible light photons to register an image. Fig. 1 is a plot of the night sky spectral irradiance and this shows that the photon rate in the region from 800 - 900nm is five to seven times greater than in the visible region around 500nm. Fig. 2 plots reflectivity of various materials against wavelength. Note that reflectivities rise in the near IR and that for green vegetation reflectivity is four times higher between 800nm and 900nm than at 500nm. Therefore, at night, more light is available



1 ***Night spectral irradiance***

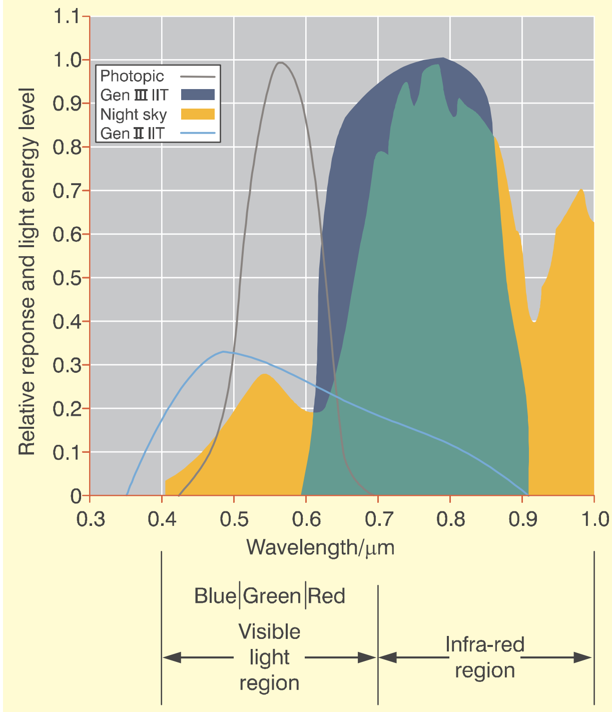


2 ***Reflectivity of various materials***

in the near IR than in the visual band and that against certain backgrounds, notably green vegetation, more contrast is available.

Image intensifiers provide a means of taking advantage of this situation by effectively amplifying the available near IR light and presenting the user with an image that is sufficiently bright to be clearly visible without their being dark adapted (that is, scotopic).

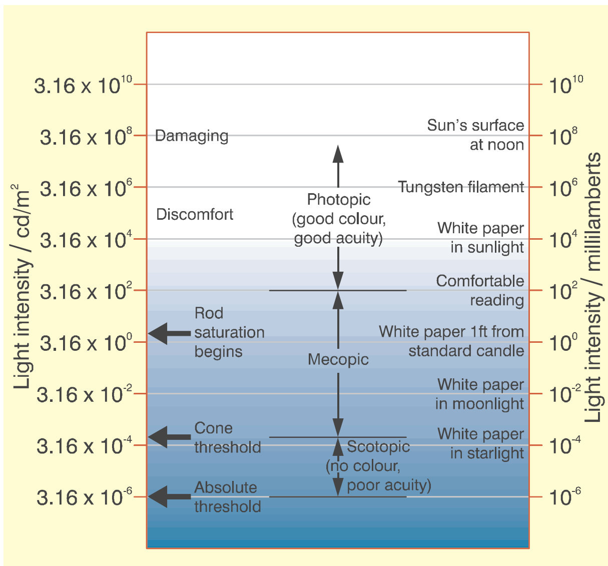
Third-generation (GEN 3) IITs are fitted with a gallium arsenide photo-cathode; this is most sensitive in the near IR and so makes maximum use of the available light and contrast information in the night scene. Fig. 3 shows the response of a typical GEN 3 image intensifier superimposed on night sky radiation spectrum. The output from the IIT is a phosphor screen that emits in the centre of the visual band, where the eye is most sensitive. The light intensity output of the IIT is mainly in the low photopic/mesopic area, that is, the user is not dark-adapted. Fig. 4 illustrates the scotopic, mesopic



3 ***Image intensifier tube (IIT) spectral response curves***

and photopic intensity bands. Fig. 3 also shows the CIE photopic curve, which illustrates the spectral response of the human visual perception system. Also shown is the GEN 2 (second generation) IIT response.

Both second-generation and third-generation IITs are used in airborne applications. Third-generation devices have better sensitivity and resolution than second-generation devices and operate over a slightly different spectral range but are significantly more expensive than GEN 2 devices.



4 ***Light intensity bands***

Night Vision Goggles Configuration

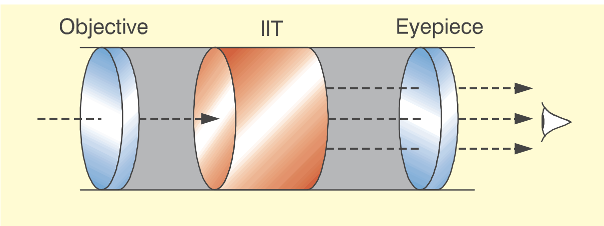
Night vision goggles were originally developed for ground-based applications and early airborne devices were derivatives of these systems. Many of these devices used a single second-generation image intensifier viewing the scene through a single objective lens. The output image is optically split and presented to each eye through two eyepieces. This bi-ocular approach was found to be unsuitable for the demanding airborne environment so airborne NVGs use two IITs to provide the pilot with a binocular view of the night scene.

These devices, for the most part, have a common configuration and their ancestry in ground-based systems is apparent. Typically, an airborne NVG comprises two monocular assemblies mounted on a bracket that is attached to the front of the pilot's flying helmet. The bracket provides the various adjustments required to align the monoculars correctly with the pilot's eyes, and also provides the interface that allows goggles simply to be clipped onto the pilot's flying helmet.

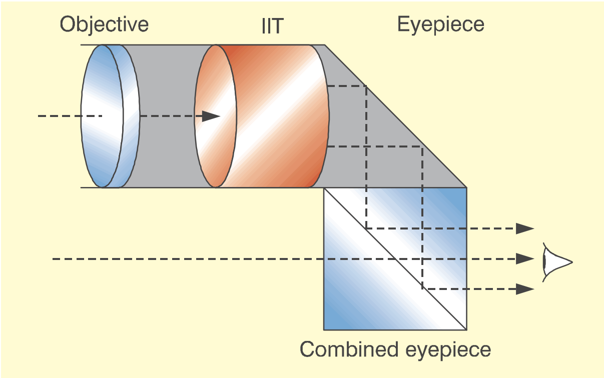
An important feature is that the power for the goggle is normally provided by batteries located either within the bracket or mounted remotely on the rear of the helmet. This means that NVG operation is completely independent of aircraft power.

Each monocular assembly has an objective lens that collects the available IR light from the outside world and focuses it onto the IIT input window (fig. 5). The objective lens also normally contains a 'minus blue' filter for compatibility with blue/green cockpit lighting. The electro-optical image is then relayed to the pilot's eye by an eyepiece assembly. Conventionally, these components are mounted directly in line with the pilot's line-of-sight (fig. 6), but can normally also be flipped up out of the way if necessary. Marconi Avionics 'Cat's Eyes' NVG provides a see-through eyepiece that combines IIT imagery with the real-world scene, providing improved view of cockpit instruments and the HUD.

NVGs are now in widespread use in a multitude of applications, including rotary wing, fast jet, transport aircraft, and ground-based applications. Fig. 7 illustrates Marconi Avionics' conventional



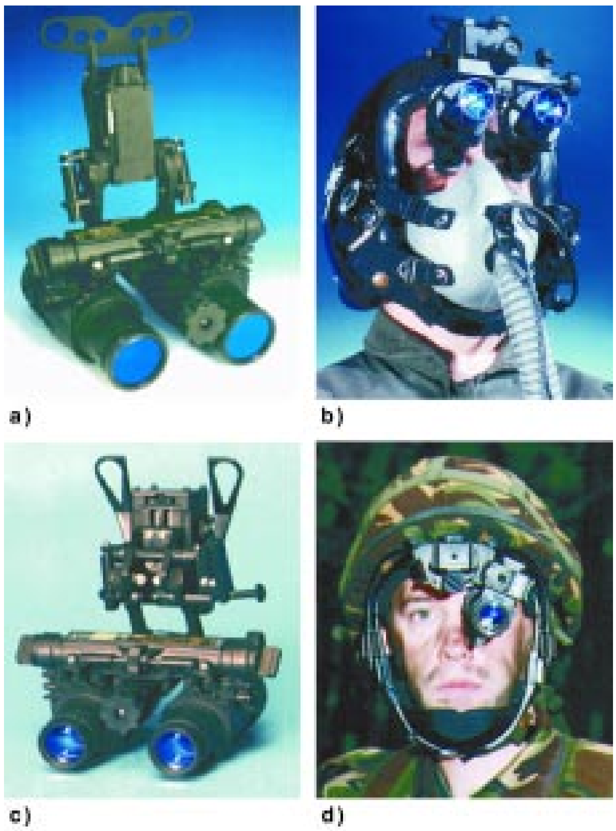
5 ***NVG monocular configuration***



6 ***Combiner eyepiece NVG***

NVG products that have been produced in large quantities and are all still in production.

Of key importance is the continual evolutionary increase in performance and capabilities in NVGs, resulting mostly from improvements in the performance of image intensifier tubes. Better resolution, enhanced performance at low light levels and improved signal-to-noise ratio make the capabilities provided by NVGs an essential element of airborne night vision systems. New NVG configurations are also being developed, such as the 'Night Viper', visor-projected ejection-



7 ***Marconi Avionics NVGs***

8 *'Night Viper' ejection-safe visor-projected NVG*

safe integrated night vision helmet (fig. 8), which is in development, offering improved performance with better helmet integration. NVGs are now a mature technology and provide very major benefits in night operations.

Why Integrated HMDs?

Ever since aircrews began flying with night vision goggles in the early 1980s, the value of display-capable helmets has been recognized, leading to the development of helmet-mounted display systems (HMDS) offering a range of capabilities for both fixed-wing and rotary-wing aircraft.

Information Display

Combat experience has shown the need to provide the aircrew with information on aircraft attitude and status that is integrated with the night scene. This is normally displayed as a non-conformal (head-stabilized) symbology overlaid on the NVG image.

Weapon Aiming

Targeting and weapon-aiming applications require the appropriate symbology and also knowledge of where the user is looking both to position symbology on the display and also to steer missile seeker, gun or sensor. Symbology in this case can be as simple as an aiming reticle but a dynamic display of conformal (or real-world stabilized) symbology provides a more flexible solution.

Navigation and Target Acquisition

This application requires a conformal display of navigation data and aircraft status information combined with a display of target (or multiple targets) symbology. This application requires a dynamic display that is normally provided by miniature cathode ray tubes (CRT), but other technologies are now becoming available.

Multi-Sensor Night Vision

Image intensifier tubes rely on ambient light to function. NVG performance is therefore degraded in conditions where ambient illumination is very low, or where there is poor contrast from the outside world scene in the near IR part of the spectrum. Hence there is a need to provide imagery from another sensor operating in a different part of the spectrum – a thermal imager (TI), for example. Conversely, in adverse thermal conditions the image quality from a TI is degraded, hence the need for multiple sensors.

Pilot Safety & Comfort

A further concern is the nature of NVGs as a clip-on accessory to existing flying helmets. In general, most current helmets were not initially designed for such applications and have been adapted to facilitate the fitting of NVGs. In many cases this combination induces pilot fatigue resulting from increased head-supported mass and poor centre of gravity. Pilot safety can also be compromised, particularly during ejection from fast jets or in crash situations in rotary-wing applications.

Cost-Effective Increase in Capability to Satisfy Operational Need.

Helmet displays broadly offer a capability in either day-only, or in 24-hour mission scenarios. The 24-hour capable systems display imagery from an associated night sensor such as forward-looking infra-red (FLIR) or image intensifier devices. Such systems naturally offer greater advantages over day-only HMDs or night vision goggles alone.

A helmet display is a most cost-effective method of upgrading an existing cockpit design, requiring little modification to the aircraft or cockpit structure in return for a significant improvement in mission effectiveness, failure survival capability and adaptability.

Integrating Helmet-mounted Displays with Night Vision Devices

The two main approaches to combining the NVG function and head mounted display are:

- optical image combination of IIT and CRT images, and
- electronic image combination using electrical output image intensifier or night vision devices

The former is currently the most widely-used technique for combining imagery from IITs and displays in head-mounted applications. This technique is used in products that simply add a display function to existing NVGs (such as the Tracor AN/AVS-7 NVG HUD) and also in more advanced integrated designs such as Marconi Avionics' 'Knighthelm' HMD.

Electronic image combination, although not new, is now becoming a practical solution for many applications and significant development activity is now focused on developing high-performance night vision cameras for use with HMDs.

Optical Image Combination

This technique involves optically combining the output of a helmet-mounted CRT or other display device with the output of the image intensifier tube at a single intermediate image plane. There are several design trades to be made in selecting the characteristics of the image combination optics, but these are dictated by the nature of the application. IITs have a low output luminance whilst CRTs are capable of a very wide luminance range. Therefore, a key characteristic is the transmission ratio of the display channel luminance and IIT channel luminance.

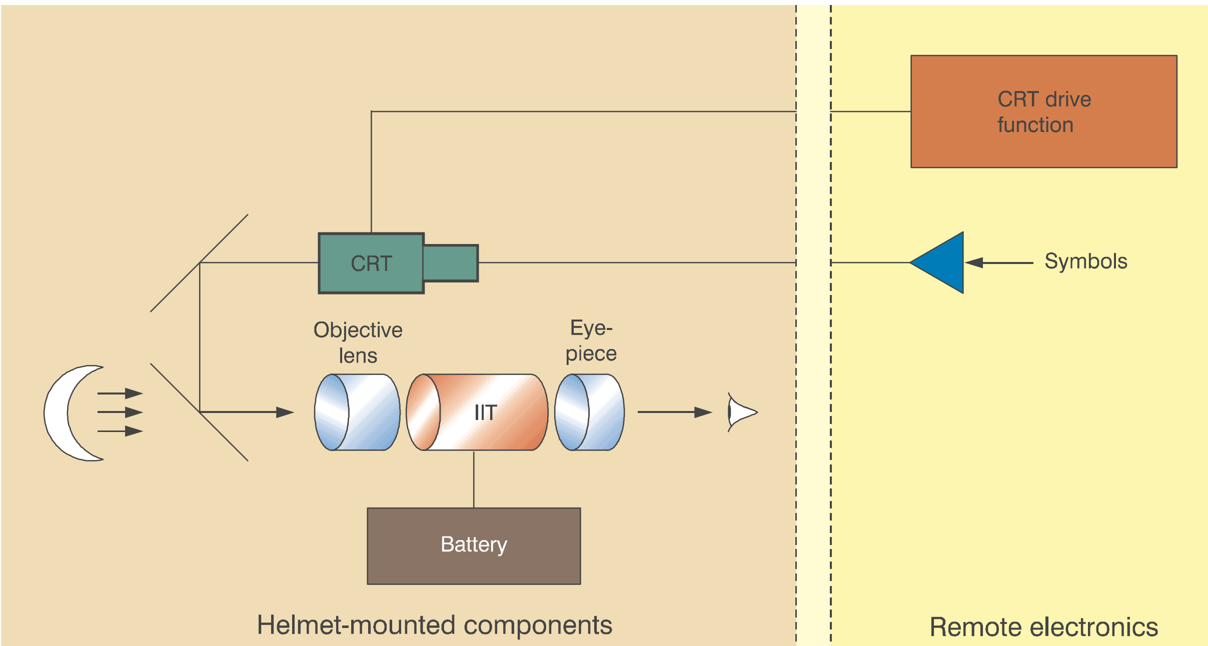
The following paragraphs describe three example systems that each use optical image combination:

AN/AVS-7 NVG HUD

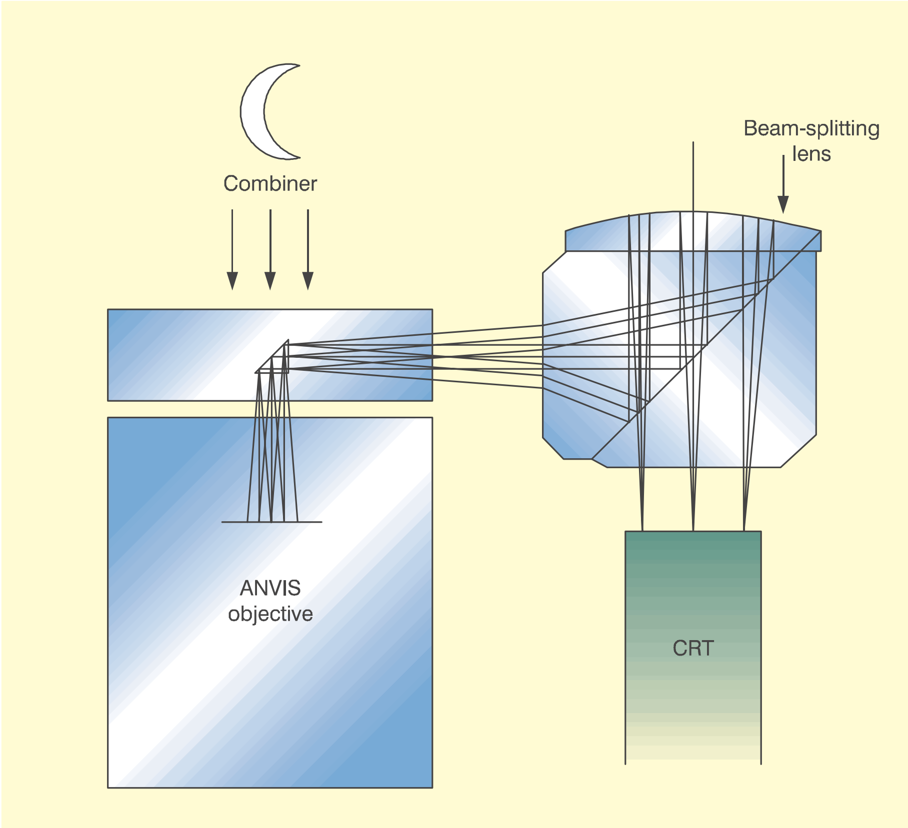
Several mishaps have been recorded when operating with NVGs in helicopters. In some types of terrain, such as undulating desert, the number of visual cues available to the pilot is reduced, or non-existent, in conditions where workload is such that there is little time to look down at cockpit instruments. This has resulted in pilots misjudging altitude and closure rates, leading to several accidents. The addition of symbology providing flight information, whilst still allowing the pilot to remain head-up, greatly improves this situation.

The Tracor [Marconi North America] NVG HUD injects a display into the standard ANVIS NVG that is seen by the user as part of the outside world scene viewed by the image intensifier. Symbology is overlaid on the NVG view of the outside world, providing the information necessary to fly the aircraft, plus additional symbology selected by the user. A block diagram illustrating the basic configuration of the NVG HUD is shown in fig. 9.

The NVG HUD uses a high-resolution 0.5 inch diameter (12.5mm) CRT to provide the symbology display. The CRT output is collimated and injected



9 *NVG HUD block diagram*



10 ***AN/AVS-7 NVG HUD optical image combination***

into the objective lens of the NVG (fig. 10). Both the symbology and the scene energy are focused onto the photocathode of the IIT by the NVG objective lens. The CRT brightness is controlled to be suitable for direct combination with the outside world scene on the photo-cathode of the IIT. The image viewed by the user is therefore a single collimated image of the symbology and the intensified night scene.

The CRT drive electronics, symbology generation and aircraft data interfaces are all housed remotely from the helmet (see fig. 11). An important feature of this approach is that the NVG operation is independent of the display function. The battery-powered goggle will therefore continue to function normally, should the display system fail.

The clip-on nature of the standard ANVIS-6 NVG is retained, albeit with the additional weight and attendant centre of gravity shift associated with the addition of the CRT and image combination optic. A key point to note is that the symbology display in this type of system is not conformal with the outside world scene, as viewed through the NVG. This could be achieved, however, by the addition of a helmet-tracking function providing helmet line-of-sight information to the graphics generator.

ANVIS E-HUD

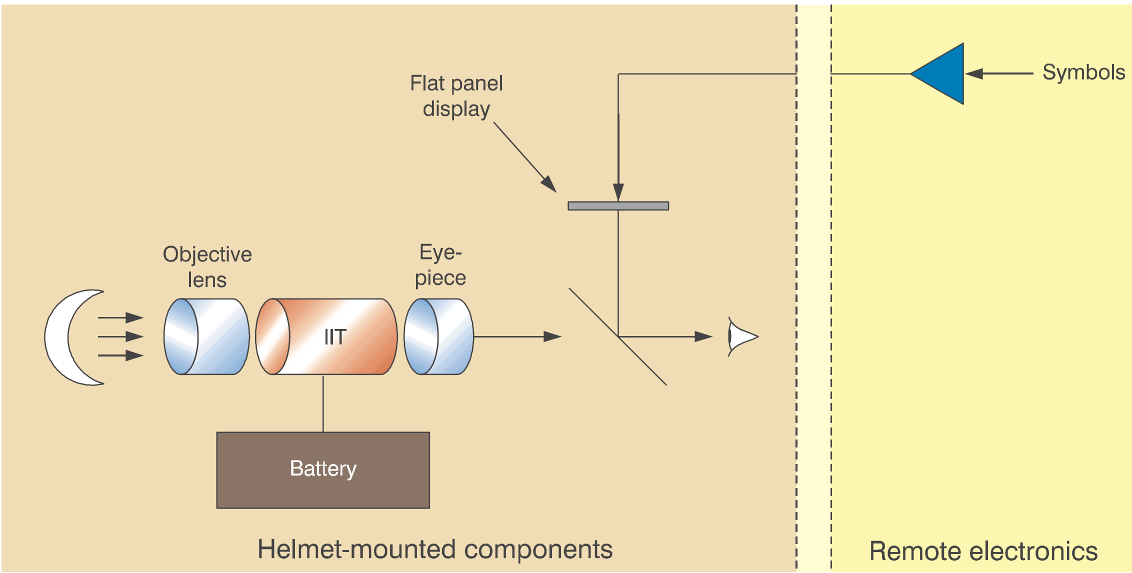
The Tracor [Marconi North America] ANVIS E-HUD also injects a display into a standard NVG but, in this case, the optical image combination takes place within the eyepiece of the NVG – that is, after the IIT has amplified the night scene. This approach provides advantages over the front injection system described above:

- The E-HUD is capable of displaying colour (amber) symbology over the green NVG scene for improved contrast against the background.
- E-HUD symbology can be displayed when the NVGs are off, or in very low light conditions.
- Reduced symbology washout when ambient light levels are increasing.

The E-HUD was initially designed with a CRT display but this has now been replaced by a miniature flat-panel device, an Active Matrix Electro-Luminescent display (AMEL). A simplified block diagram of the E-HUD is given in fig. 12.

The AMEL output is combined with the IIT output image at the beam combiner and is presented to the user as a single collimated image of symbology

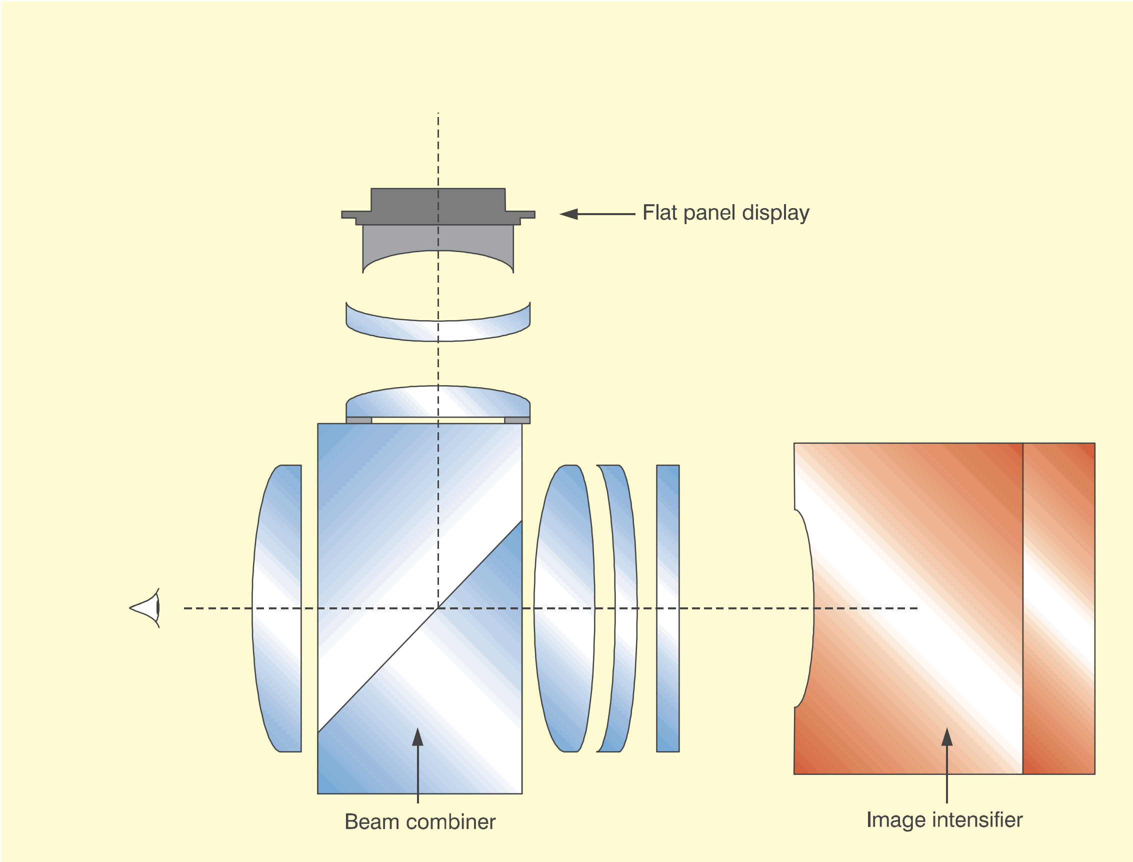
11 *AN/AVS-7 NVG HUD fitted to a flying helmet*



12 *E- HUD block diagram*

and night scene (see fig. 13). The display brightness is controlled to be suitable for combination with the intensified outside world scene on the output window of the IIT. The image viewed by the user is therefore a single collimated image of the symbology and the intensified night scene.

The clip-on nature of the standard NVG is also retained and the additional weight and attendant centre of gravity shift associated with the addition of the display is greatly reduced, compared with the CRT variant. Also, the compact nature of the display injection into the eyepiece allows a 25mm eye relief to be maintained and allows the modified eyepiece to be easily interchanged with a standard eyepiece. Fig. 14 is a photograph of the E-HUD fitted to a standard NVG.



13 ***E- HUD optical image combination***

14 ***E- HUD fitted to standard NVG***

Knighthelm Integrated Helmet-mounted Display

The NVG HUD exploits and enhances the utility and availability of existing NVGs but is currently limited to providing an information display. Also the weight and centre of gravity of the head-mounted components can be fatiguing and compromises safety in some applications. A more integrated approach is required to combine advantages of NVGs with a display function to provide a true 24-hour operational capability. This is essential where a second sensor – such as FLIR – is to be displayed and when the system is required to operate in day (symbology only) and night (multi-sensor night vision and symbology).

The 'Knighthelm' HMD has been developed to provide the user with a display that can be used in both day and night conditions during a single mission without the need to reconfigure the HMD. Key features of the design are:

- binocular display integrated with a lightweight purpose-designed flying helmet;
- dual sensor display capability: image intensifier tube or thermal imager with ability to switch instantly between image sources as required;
- symbology display overlaid on real-world scene or sensor image; and
- operation in both day and night flying conditions.

The principle of the Knighthelm HMD optical system is illustrated in fig. 15. In this approach the image intensifier output is optically combined with the CRT imagery in such a way that IIT imagery transmission is maximized whilst retaining a daylight compatible CRT display of symbology and FLIR imagery. A relay lens then routes the combined image to the combiner eyepiece where it is viewed by the user as a collimated image superimposed on the normal line of sight. This approach exploits all of the performance available from current GEN 3 IITs to provide excellent night vision with symbology overlay. The display has a 1:1 correspondence with the real-world scene.

A significant benefit of this approach is that the IITs may be powered either from aircraft power or from a small helmet-mounted battery pack providing night vision independently of aircraft power. The CRT may also be used to display FLIR imagery from a head-steered FLIR, providing a true multi-sensor capability within one optical system.

In designing optics for HMDs, optical performance is only one of several design criteria. Lowest possible mass is achieved by minimizing the number of optical components, by using plastic elements where possible, and by the use of advanced lightweight materials. Durability is essential and has involved careful design of the mechanical structure to maintain the structural integrity of the optical system under mechanical and thermal stresses.

The resultant Knighthelm HMD (shown in fig. 16) has now completed an extensive flight-test programme that has demonstrated a high level of performance, both in day and night missions. The optical combination of symbology with the IIT imagery has greatly enhanced the mission effectiveness compared with existing in-service NVGs; and the ability to switch instantly between the head-steered FLIR and the intensifier image gives the system a very high level of operational availability in all conditions, day or night.

Electronic Image Combination

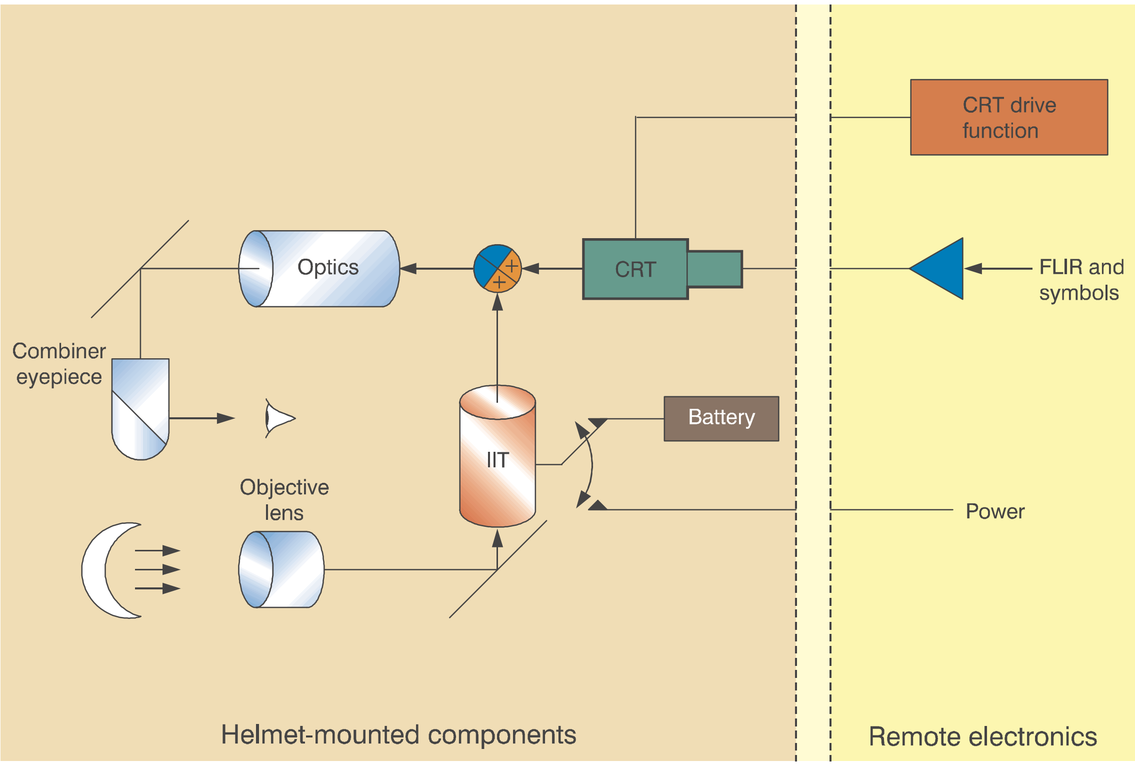
The principle of electronic image combination is illustrated in fig. 17. In this approach, enhanced night vision is provided by a miniature helmet-mounted night vision camera. This is typically an image-intensified CCD camera, although other techniques are in development.

The output of this is a video signal that is fed back to the remote display drive electronics where it is electronically combined with the symbology and displayed on the helmet-mounted CRTs in the normal way. The advantage of this approach is that it maximizes the performance of the CRT display by removing the need to mix IIT and CRT imagery optically. This also reduces head-supported mass and bulk, which are critical in fast jet applications and in small cockpits.

Although this approach still utilizes image intensifier technology the intensified imagery is now presented in a raster format, allowing the potential to enhance the night vision image, improving image contrast and reducing some of the unsatisfactory characteristics of directly-viewed IITs such as image blooming.

Using the example of the featureless desert terrain, the ability to enhance the image contrast electronically allows the user to see undulations in the terrain not visible using conventional NVGs. Similarly, a bright point source of light viewed by a conventional NVG results in a halo effect that blots out the surrounding scene. This effect can be eliminated, allowing the user to view clearly a scene containing bright sources of light, such as street lights.

However, the performance of current night vision cameras in terms of resolution is inherently



15 ***Optical mixing of IIT and CRT imagery***

16 ***The 'Knighthelm' 24-hour HMD***

lower than that provided by the best NVGs. This is largely a function of the conversion of the optical image into a video signal for presentation on the helmet-mounted CRT display. Night vision camera resolution performance, therefore, has to be considered in the context of complete system performance – that is, from camera through to CRT on the HMD – as there are many non-linear factors that affect performance.

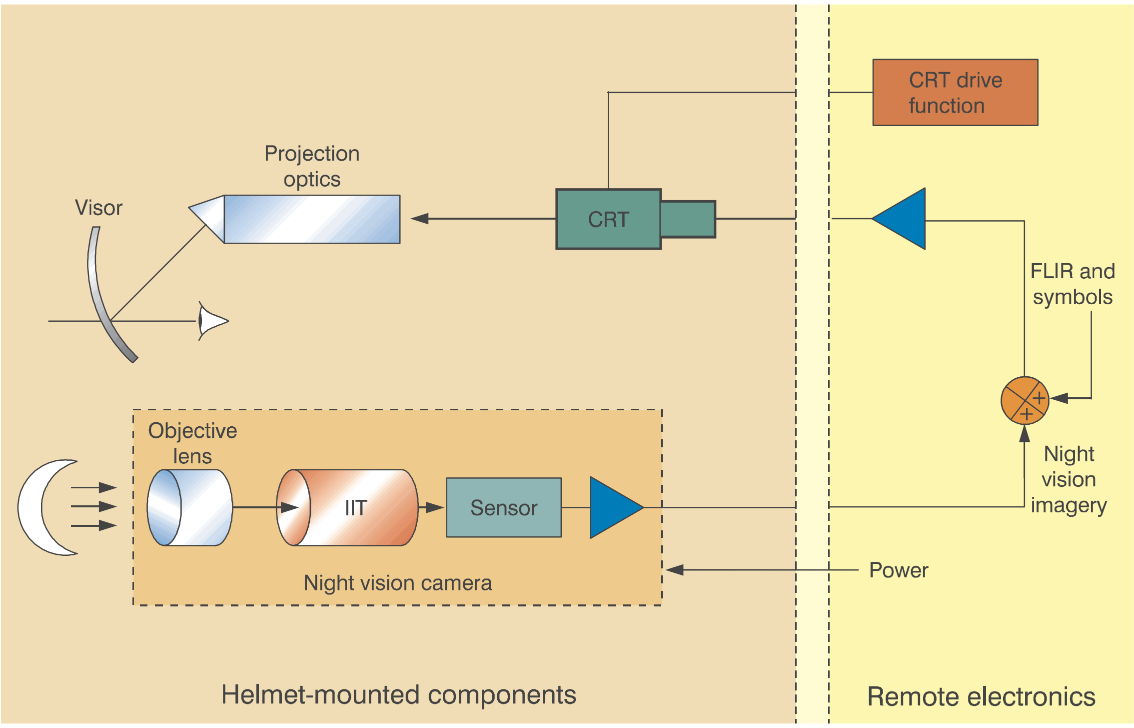
In summary these are:

- image intensifier resolution vs. light levels,
- sensor (typically a CCD) resolution,
- display system video processing, and
- CRT resolution.

The following table is a summary that trades these factors against resolution performance:

TABLE 1
Factors Affecting Resolution Performance

Factor	Affected by	Effect
Intensifier resolution	Scene illumination	System resolution decreases as scene gets darker
Sensor resolution	Number of sensor pixels	Number of pixels limits maximum system resolution
Display system video processing	Display electronics bandwidth, cable losses, etc.	Inadequate electronics reduces system resolution
CRT resolution	CRT bandwidth	Inadequate CRT resolution reduces system resolution



17 *Electronic combination of IIT and CRT*

Scene illumination levels must also be taken into consideration when evaluating typical system operating performance. Peak resolution is achieved when intensifiers are illuminated with scenes brighter than many typical mission scenarios. As the scene illumination reduces to clouded moonlight, for example, system resolution will have significantly reduced because of the drop-off of resolution from the intensifier.

Developments now underway are solving these problems to provide very high performance night vision cameras. These, when combined with a high-performance HMD, provide the user with performance that matches existing in-service NVGs and has the potential to overcome some the limitations of the goggles.

Figs. 18,19 and 20 are illustrations of three HMDs that incorporate electronic image combination to provide night vision. These are all now under development within Marconi Avionics for both fast jet and rotary wing applications.

The 'Crusader' HMD is part of a technology development programme aimed at providing helmet solutions that can be applied into several fast jet and rotary wing applications. The variant illustrated provides a full day and night multi-sensor binocular display of symbology overlaid on sensor imagery from dual helmet-mounted night vision cameras, or from an external FLIR.

18 *'Crusader' binocular visor-projected helmet-mounted display*

The 'EF 2000' HMD is in full-scale development to meet requirements for day and night applications, combining the qualities of helmet cueing systems with the display of full flight symbology and multi-sensor imagery from FLIR and the on-helmet night vision cameras.

The 'Helicopter' HMD is in development for the AH-12 upgrade programme in the USA and will be used to provide very high quality night vision to the aircrew, combined with flight and weapon aiming symbology in both day and night missions.

19 *'EF2000' binocular visor-projected helmet-mounted display*

20 *'Helicopter' visor-projected helmet-mounted display*

Conclusion

Night vision goggles are now in widespread use in many airborne applications. They are a mature technology and offer significant operational benefits in night mission by providing the aircrew with greatly enhanced night vision. Their limitations are also well understood and this, combined with operational experience, has resulted in a drive to enhance NVGs by adding a display function. This paper has provided an overview of methods of achieving this using optical image combination techniques and has also discussed several practical implementations that are currently in service.

This paper has also discussed the extension of the basic concept into day and night integrated helmet displays combining the functions of the NVG with those of the HMD, using both optical and electronic image combination methods. Integrated helmet systems of this type offer a major increase in capability and mission effectiveness in all-weather 24-hour applications, which belies the relatively modest costs involved in installing HMD systems in aircraft. The technologies required to implement these products are either already available or are in an advanced stage of development.

Acknowledgements

This paper is based on work presented at Night Vision '98. The products and technologies discussed within this paper have been developed by many groups from across Marconi Electronic Systems, including Tracor, Marconi Avionics in Edinburgh and Rochester, the Marconi Research Centre, and EEV Ltd.

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Achieving 20cm Positioning Accuracy in Real Time Using GPS – the Global Positioning System

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Marconi Canada (part of the Marconi North America Group of Marconi Electronic Systems) is a recognized world leader in the design, manufacture, sale and support of high-technology electronic products for the aerospace and communications market, for both military and commercial applications. Its headquarters and principal design and manufacturing facility is located in St-Laurent, Quebec (in the greater Montreal area). Its facilities include a branch plant in Kanata, Ontario (in the Ottawa area), as well as sales and service offices across Canada. A photograph of the Company's headquarters is presented in fig. 1.

Marconi Canada is a pioneer in the design and manufacture of GPS receivers. The first receiver development took place in the early 1980s with a military receiver development for the Canadian Department of National Defence. Then, in the mid-1980s, the first commercial GPS receiver was developed. The next major development took place in the early 1990s for a GPS receiver to be installed on the new Boeing 777 aircraft. This marked the beginning of a series of successes for Marconi Canada in the commercial avionics market, and the Company is now recognized as a world leader in this area.

In the mid-1990s, a new group was created with the objective of porting our GPS technology on low-cost hardware platforms. This initiative has been a success as well, with the development of a variety of products targeted towards the consumer market, namely: automatic vehicle location systems, marine navigation, golf yardage systems, surveying systems, and also some military applications requiring commercial off-the-shelf (COTS) solutions.

1 ***The headquarters of Marconi Canada***

Glossary

ASIC	Application Specific Integrated Circuit
DGPS	Differential Global Positioning System
FEPROM	Flash Erasable Programmable Read-Only Memory
IF	Intermediate Frequency
I/O	Input/Output
OEM	Original Equipment Manufacturer
PVT	Position, Velocity and Time
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
RTK	Real-Time Kinematic
UART	Universal Asynchronous Receiver/Transmitter

Introduction to GPS

The NAVSTAR (NAVigation Satellite Timing And Ranging) Global Positioning System, better known as GPS, is a radionavigation system using a network of satellites distributed over six orbital planes. GPS provides accurate 3-D position, velocity and time information, and world-wide 24-hour coverage to an unlimited number of users with all-weather operation. GPS is a one-way ranging system: signals are transmitted only by the satellites. Each GPS satellite transmits signals centred on two microwave frequencies: 1575.42 MHz, referred to as Link 1, or simply L1; and 1227.60 MHz, referred to as L2.

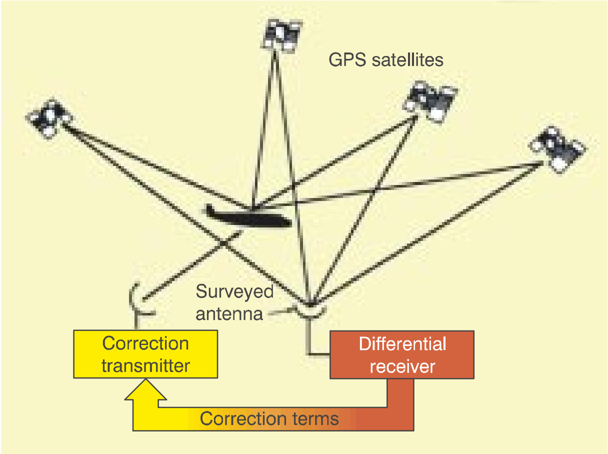
The L1 signal is modulated with (i) the Coarse Acquisition (or C/A) Code, a coarse ranging signal; (ii) the Precise (P) Code, a precise, but encrypted, ranging signal; and (iii) navigation data at 50 bits per second. L2 is modulated only with the P-Code and the navigation data. Authorized users only (U.S. Department of Defense and allies) have access to the decryption keys of the P-Code, which by its nature has much higher anti-jamming properties than the C/A-Code. Using the ranging signal and the navigation data, a GPS receiver can measure the range between the satellite and the receiving antenna, and compute the exact position of the transmitting satellite. Hence, with three satellites, the 3-D position of the receiver may be computed, and a fourth is required for solution of the time. An excellent overview of the GPS system operation is given in reference (1).

Code Differential GPS Overview

Code Differential GPS (Code DGPS) is the regular Global Positioning System with the addition of a differential signal that conveys correction data. These data significantly increase the accuracy of the GPS navigation function and can be broadcast over any authorized communication channel. In these systems, a GPS receiver is located at a known (surveyed) position: this receiver is usually referred to as a reference station. The reference station makes measurements on the satellite's signal and estimates the measurement errors using its surveyed geodetic position. The errors include the signal transmission delays caused by the ionosphere and the troposphere, as well as Selective Availability (S/A) – an intentional signal degradation introduced by the U.S. Department of Defense, in an effort to restrict the accuracy capability of most civilian GPS users.

In layman's terms, because the reference station knows precisely where it is and computes a different position using the GPS signals, it can estimate the errors in its signal measurements. These errors, or differential corrections (that is, the difference between the true range and the measured range), are then transmitted to roving receivers by radio or other means. They can then be applied to GPS measurements from the roving GPS receiver, and used to remove the systematic (correctable) error factors, because most of these errors will be similar for the roving receivers. Note that the correlation factor between errors observed at both sites largely depends on the distance between the two receivers.

A DGPS system therefore consists of at least two units: a reference station and one (or several) roving units. The reference station broadcasts its differential data and the roving units receive it through a data port, directly connected to a radio receiver. The roving units can then display position, velocity, time (PVT) and other information, as needed for their marine, land or aeronautical



2 ***Code Differential Global Positioning System (DGPS) example***

applications. A DGPS system implementation is depicted in fig. 2 (note that the reference station is located on the ground and the roving unit is located in the aircraft).

Carrier Differential GPS Overview

A different, and more accurate, differential correction technique involves tracking of the satellite signal's carrier phase, and is called carrier-phase DGPS. When a receiver navigates in carrier-phase mode, it is measuring a different GPS observable, namely the GPS carrier wave. To do so, it must measure the phase of the carrier continuously from signal lock time, t_0, in order to produce the following observable:

$$\phi_m(t) = \phi(t = t_0) + \int_{t_0}^{t} f dt, \quad (1)$$

where ϕ is the received carrier phase and f is the received Doppler frequency.

In order to produce a range measurement between the satellite and the user, the following observable must then be formed:

$$\rho^{\phi}(t) = N_0 + \phi_m(t), \quad (2)$$

where N_0 is an exact number of cycles between the user and the satellite at time t_0. ϕ_m thus represents the change in cycles since time t_0.

However, the initial number of wavelengths N_0 between the satellite and the receiver is unknown. This is called the **carrier phase ambiguity** and must be estimated. In order to estimate this ambiguity, it is necessary for the roving GPS unit to use information (that is, carrier-phase measurements) from a reference station. This technique yields accuracies in the cm-range in dynamic environments and is called 'Real-time Kinematic', or RTK, GPS. A rather good (albeit brief) introduction to code and carrier-phase DGPS is presented in reference (2).

System Specifications

The RTK-capable engine developed by Marconi Canada, called the RT•Star, consists of single-frequency (L1) RTK Navigation software residing on a low-cost hardware platform for embedding in Original Equipment Manufacturer (OEM) systems. It measures 4" × 2.65" (100 mm × 67 mm) and consumes 2W. Details of its use, performance and specifications are presented in reference (3). This product is considered to possess one of the highest accuracy-over-price ratios in the OEM sensor industry.

The RT•Star can be configured either as a reference station or a roving unit via a command message. Communication between both is implemented via a standard radio link and the information is encoded in RTCM-104 format[4]. Communication from a host computer with the GPS engine is performed via a serial port using an RS-232 Marconi-proprietary transmission protocol. The reference station is also capable of self-surveying its position.

The RT•Star has the following features:

- 12 parallel tracking channels;
- GPS measurements sampling aligned on GPS time one-second roll-over event;
- raw measurement output rate of 10 Hz;
- time mark signal output aligned on GPS time one-second roll-over event;
- keep-alive input pin (RAM and/or real-time clock);
- dual UART (third UART optional);
- six input/output discrete control lines;
- reprogrammable operational code (FEPROM); and
- rechargeable lithium battery (optional).

The RT•Star is compatible with both active and passive antennas.

System Architecture

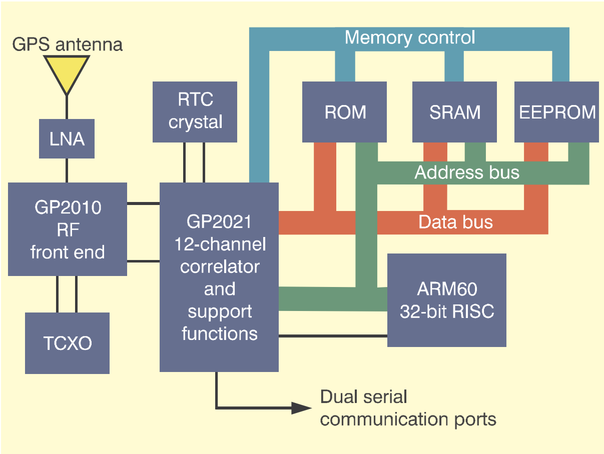
Hardware Overview

The RT•Star hardware is a highly integrated design built around three components[5]:

- RF front-end,
- digital signal processing (DSP) ASIC, and
- RISC processor.

Fig. 3 depicts a block diagram of the receiver.

The RF chip, preceded by a low-noise amplifier (LNA), performs a triple IF conversion, from 1575.42 MHz to 4.3 MHz, and a 2-bit analog-to-digital conversion.



3 *Receiver block diagram*

The temperature-controlled crystal oscillator (TCXO) is the receiver's reference oscillator.

The DSP chip includes a 12-channel GPS signal correlator and the following peripheral circuits:

- two programmable UARTs;
- real-time clock;
- programmable interrupts;
- watch-dog and reset circuit; and
- discrete I/Os.

The processor is the system's critical component. The ARM60 RISC processor was selected because it has:

- the processing power to handle 12 tracking channels;
- 30% spare capacity for customer-specific tasks; and
- low cost and power consumption.

Software Overview

The embedded software was developed using object-oriented design and programming techniques in order to yield reusable software components and to encapsulate the functions most subject to change. The major objects encapsulate the following functionalities:

- Signal Processing;
- Satellite List Management;
- I/O Management;
- Differential Data Processing; and
- Navigator.

The Navigator is the ultimate recipient of the work produced by the other objects: it receives all the data (measurements, differential data, satellite data...) and produces a PVT estimate.

Navigator Overview

A comprehensive description of the Navigator's algorithms is presented in reference (6). Only a brief overview is presented below.

One of the first steps to be performed in an RTK Navigation solution is to form two sets of observables: the single and the double-differences[(2)]. Both are derived using the carrier phase observable, which is defined as:

$$\rho^{\phi} = R + c(\Delta t^{u} - \Delta t^{s} - \Delta iono + \Delta tropo) + \epsilon^{orbit} + N_0 \lambda + \eta_{\phi} , \quad (3)$$

where:

- R is the true range between satellite and user;
- c is the speed of light;
- Δt^u is the user's clock offset from true time;
- Δt^s is the satellite's clock offset, including relativistic effects;
- $\Delta iono$ is the total ionospheric advance (the dispersive property of the ionosphere on the carrier actually causes an advance of the signal with respect to the modulated code);
- $\Delta tropo$ is the total tropospheric delay;
- ϵ^{orbit} is the error introduced by the orbital data;
- N_0 is the initial carrier phase ambiguity;
- λ is the signal's wavelength (19 cm for L1); and
- η_ϕ is the error caused by the receiver thermal noise; it is a Gaussian process with zero mean.

Note that in eqn. (3), R is the true range between the satellite and the user. Geometrically, this can be expressed as:

$$R = \sqrt{(x^s - x^u)^2 + (y^s - y^u)^2 + (z^s - z^u)^2} , \quad (4)$$

where x^s, y^s, z^s are the satellite's coordinates as provided by the satellite's navigation data and x^u, y^u, z^u are the unknown user's coordinates.

A single-difference across satellites is defined as the instantaneous difference in the carrier phase measurement made by the same receiver observing two satellite signals simultaneously. The single-difference operator is denoted as ∇. From n satellites $(n-1)$ single-differences can be formed. The simplest way of forming these $(n-1)$ observables is by selecting a reference satellite, s^*, and applying the operator ∇ as follows:

$$\nabla\phi_{s^i,s^*} = \phi^u_{s^i} - \phi^u_{s^*} , \quad (5)$$

where $\phi^u_{s^i}$ represents the phase measurement by the user of satellite i.

Expanding eqn. (5) using eqn. (3) shows that the receiver clock errors are removed in the resulting single-difference observable.

To form the next observable, a double-difference, a set of $(n-1)$ single-differences must be formed with measurements from the roving user. Hence a set of $(n-1)$ single-differences are formed with measurements received by the reference station on the differential link. A double-difference would read as follows:

$$\Delta\nabla\phi^{r,u}_{s^i,s^*} = \nabla\phi^r_{s^i,s^*} - \nabla\phi^u_{s^i,s^*} . \quad (6)$$

The property of this observable is that satellite clock errors are removed. Expansion of eqn. (6) with eqns. (3) and (5) yields an equation in which the unknowns are:

- $\Delta\nabla R$, the value of the geometric distance of the double-difference across satellites and receivers;
- $\Delta\nabla iono$, the value of the double advance of the carrier because of the ionosphere across satellites and receivers;
- $\Delta\nabla tropo$, the value of the double-differenced delay of the carrier because of the troposphere across satellites and receivers;
- $\Delta\nabla N_0$, the double-differenced ambiguity expressed in cycles (it is itself an integer since it is the algebraic sum of four integers);
- $\Delta\nabla\epsilon^{orbit}$, the value of the double-differenced orbital errors across satellites; and
- $\Delta\nabla\eta_\phi$, the double-differenced phase noise (the sum of four Gaussian processes with zero mean).

Because $\Delta\nabla\eta_\phi$ may be neglected if the receiver has relatively low phase noise, as well as $\Delta\nabla\epsilon^{orbit}$ (beyond the scope of this text), and because $\Delta\nabla iono$ and $\Delta\nabla tropo$ may be modelled, only $\Delta\nabla N_0$ remains to be properly estimated in order to solve for R. Fortunately, N_0 is a constant, hence it may be estimated over time using the carrier phase observables.

So, as we can see, a set of synchronized carrier phase measurements (that is, measurements that are sampled at the same time) from the reference station and the roving unit is required at the latter. One problem which arises is that the data link that provides the carrier measurements from the reference station has a given transmission latency. Consequently, the roving unit will receive its reference measurements with a typical latency of 1 to 2 seconds. Because a Navigation solution is required for the current time, the roving unit will have to have some means of extrapolating the reference measurements for the current time (that is, coincident with the unit's measurement time); then time-matched double-differences can be produced. This extrapolation process is implemented using Position-Velocity-Acceleration (PVA) tracking filters, which are not discussed here, but interested readers may find details on these filters in reference (7).

One realizes that the estimated state vector X is composed of two basic sets of parameters:

$$X = \{User\ Model \mid Measurement\ Model\}$$

The observability on these two sets is quite different. The user model represents the dynamics of the roving user. This set must be updated at the basic rate of the Navigator. However, the measurement model builds its observability on the change of geometry of the satellites that compose the unknown ambiguity. A fast update rate will not significantly improve the observability on the measurement model because of the high accuracy of the carrier phase measurements.

The Navigation function is therefore separated into two processes:

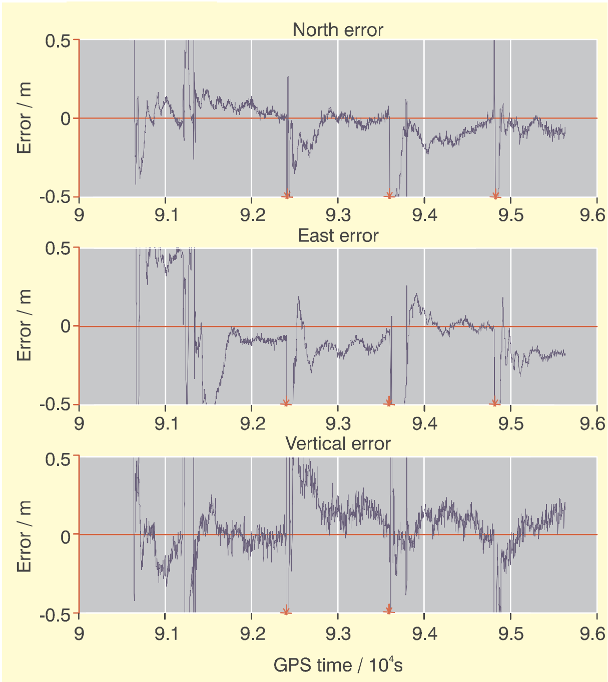
- a Kalman filter that acts upon reference station and roving unit measurements sampled at the same time. Because of the data link latency, this solution is typically old by a few seconds. This filter is referred to herein as the 'Off-Line Filter'; and
- a Kalman filter that acts upon extrapolated reference station measurements and roving unit measurements sampled for the current time. The update rate of this filter is currently at 1Hz. It is referred to herein as the 'On-Line Filter'.

These findings therefore suggest that the purpose of the Off-Line Filter is to estimate the ambiguity vector (measurement model) in the background. Because the dynamics of the ambiguities are very small (they tend towards constants), this filtering can be executed at a rate significantly lower than the required navigation rate.

The On-Line Filter is thus used to provide user PVT estimates at the nominal navigation rate. It will use the ambiguity vector computed by the Off-Line Filter.

Static Tests

A series of tests was carried out using three surveyed antennas located on Marconi Canada's roof, in order to establish the accuracy, convergence time and functional behaviour of the RT•Star in static mode.



4 *Sample reset test*

Repeatability and convergence time were tested by forcing a system reset every 20 minutes over a period of 24 hours. A sample of one reset test is shown in fig. 4. The reset times are marked with a cross on the time axis. It is observed that the system repeatedly converges towards zero error.

Table 1 shows some statistics generated from the results. The 3-D r.m.s. error reaches 20 cm after approximately 7 minutes.

TABLE 1

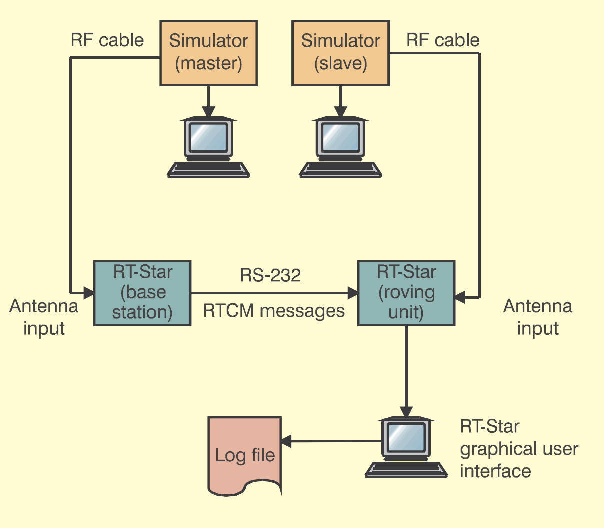
Reset Tests Statistics

Time after reset (minutes)	North r.m.s. error (cm)	East r.m.s. error (cm)	Vertical r.m.s. error (cm)
5	23	8	12
10	8	6	8
20	7	3	6

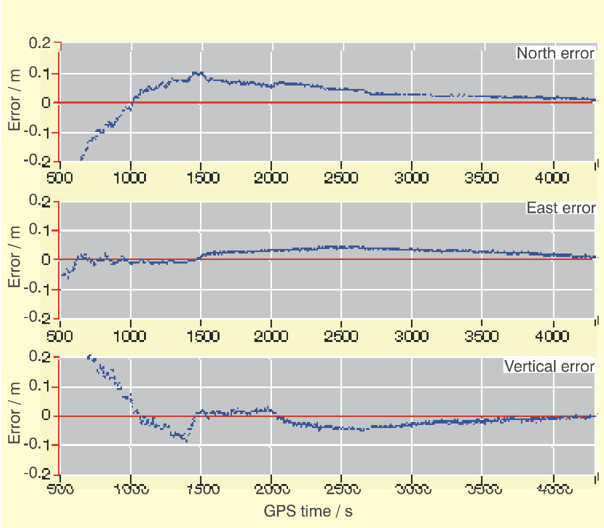
Kinematic Tests

Two types of kinematic tests were performed:

- GPS signal simulator tests to verify the absolute accuracy of the solution; and
- field tests to verify real-life accuracy and functionality of the system.



5 Simulator test set-up



6 Simulator test position errors

GPS Signal Simulator Tests

The purpose of the simulator test was to verify the accuracy of the RT•Star in a normal dynamic environment. Two Nortel model STR2760 GPS signal simulators were set up in differential mode to carry out this test. Fig. 5 depicts the test set-up.

The test simulates an aircraft performing dynamic manœuvres. The scenario is as follows:

- the aircraft is static for 10 minutes;
- it accelerates linearly with a 1g acceleration up to 100 m/s;
- it climbs to an altitude of 1 km;
- it then completes a square path at a constant speed of 100 m/s with 10 minutes between each turn;
- it touches ground and decelerates to 0 m/s; and
- it remains static for 5 minutes.

The position solution generated in real time by the RT•Star was logged and then compared to the truth file of the simulator, which is a file containing the true vehicle position at each GPS second. The results were processed with the MATLAB™ data analysis tool (provided by the MathWorks Inc.) and the North-East-Down position errors are presented in fig. 6.

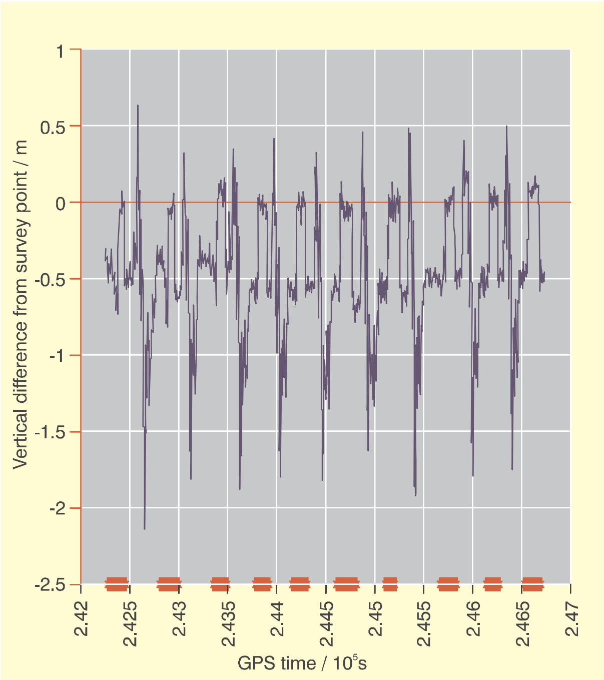
Field Tests

The purpose of these tests was to verify the accuracy and the functionality of the RT•Star in a real-life environment. Several kinematic baseline tests were performed using a reference station located on the Company's roof and a vehicle equipped with an antenna and an RT•Star. The vehicle followed a route located in an urban zone with a surveyed geodetic marker situated on the route. The test procedure is as follows:

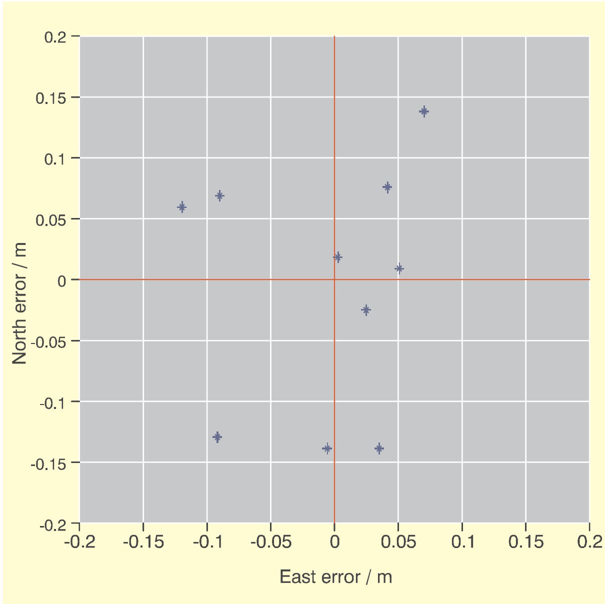
- the antenna is fixed to a surveying rod set on top of a geodetic marker located in front of the Company building;
- system is powered-on and remains static for 2 minutes;
- the antenna is relocated on the vehicle's roof (the operator triggers a signal that logs the time at which the antenna is removed);
- the vehicle drives around the Company site and stops at the geodetic marker;
- the antenna is removed from the rooftop and set on top of the marker (the operator triggers a signal that logs the time at which the antenna is set);
- the antenna remains static for approximately 2 minutes, the operator triggers the removal time log and relocates the antenna on the vehicle.

The above routine was repeated ten times.

Fig. 7 shows the position in the vertical plane. The red marks on the time axis represent the periods at which the antenna was located on the survey point. It is observed that repeatable results are obtained at each run.



7 *Vehicle vertical difference*



8 *Horizontal position error on survey point*

The error in the horizontal plane of the computed position of the marker at each run is presented in fig. 8.

Conclusions

The tests conducted on the RT•Star show that 20 cm positioning accuracy can be obtained in real time using GPS. Furthermore, the results have been proven to be repeatable.

The RT•Star (fig. 9) is considered an excellent trade-off between low-cost code differential GPS systems delivering 1 metre accuracy levels and high-end two-frequency RTK systems offering an accuracy level of only a few centimetres. It is suited for a variety of applications, namely precision agriculture, aircraft positioning and machine control. It also gives the user the flexibility to configure the receiver either as a reference station or a roving unit via a command message.

Acknowledgement

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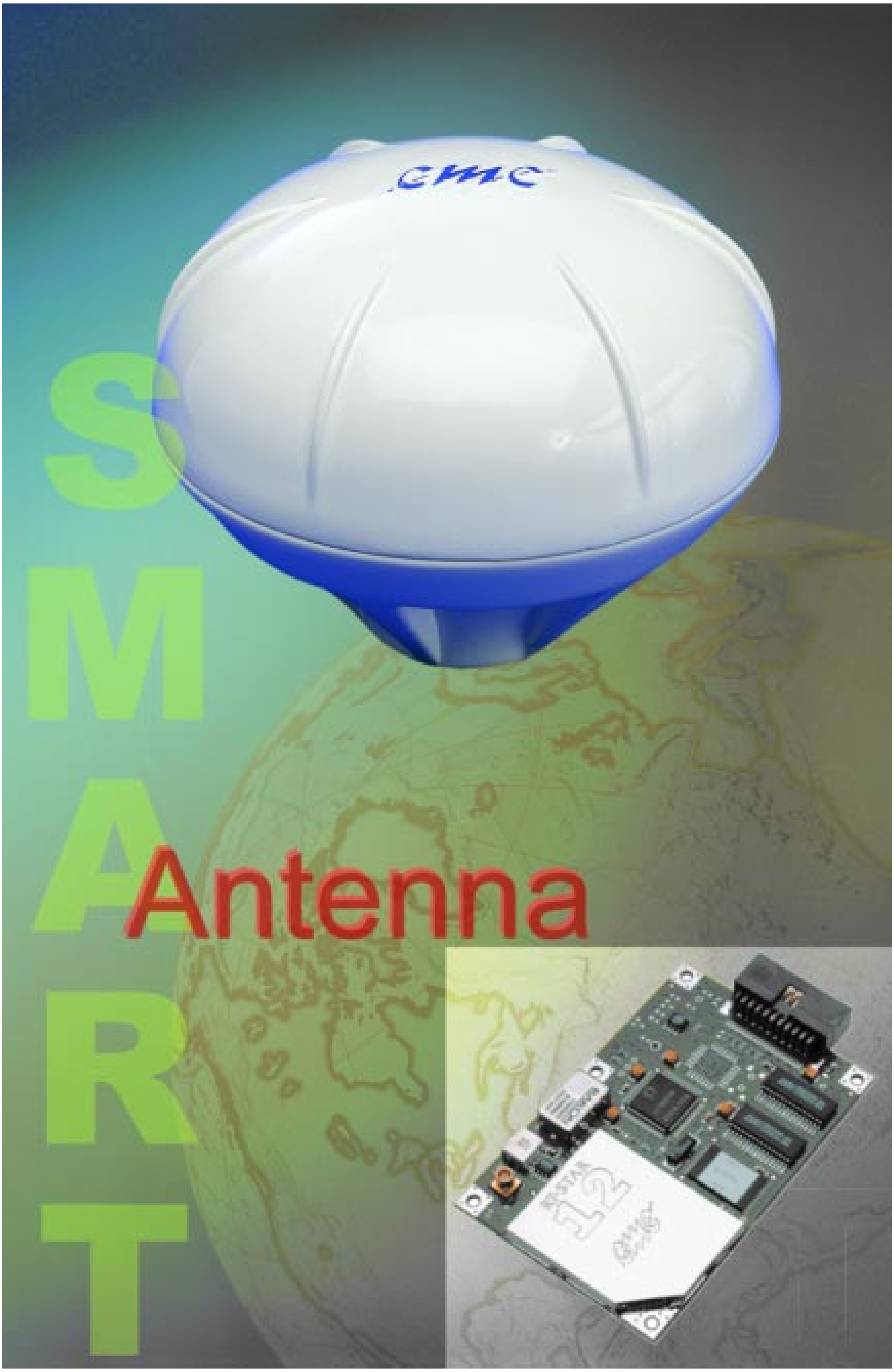

9 ***The RT•Star smart antenna unit: an RT•Star (shown inset) embedded in a GPS antenna***

The SIMTEC Simulation Framework

by D. F. BUCKLE, B.Sc., M.Sc.
EASAMS Defence Consultancy

SIMTEC† is a large C++ object oriented (OO) simulation framework developed by EASAMS Defence Consultancy and sponsored by Weapons Sector of DERA Farnborough. Although it was developed to meet the sponsor's requirement to study electronic combat in particular, SIMTEC is a general-purpose simulation tool capable of addressing a wide range of scenarios. This paper provides a short summary of SIMTEC and its potential benefits to its Users and Developers.

The paper makes two main points:

- SIMTEC is a large model that can represent many different types of interaction between military units in simulated battlespaces at a variety of fidelity levels; and
- SIMTEC is an initiative in software re-use, with several innovative techniques being applied so that the software can be used to produce a wide range of new applications – and to ensure that each new application can work with all the others.

Thus, SIMTEC provides Users with immediately useful functionality and is also a major enabling capability for Developers wishing to produce new simulations.

The paper explores the above two points by summarizing the current functionality of SIMTEC and giving an overview of the techniques used to achieve reusability. The paper argues that, in order to achieve the full benefits of reusability, it is necessary to establish a pool of Users and Developers who employ the same framework, and that framework must combine the benefits of:

- a library of reusable components;
- 'plug-and-play' interfaces* to co-ordinate the operations of models constructed from these components;

† SIMTEC is the **SIM**ULATION **T**ool for **E**lectronic **C**ombat

* 'Plug-and-play' interfaces are defined protocols that allow different modules or programs to work together whilst being treated as 'black boxes'.

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- techniques to permit models to be adapted by data configuration wherever possible; and
- the use of commercial off-the-shelf (COTS) tools.

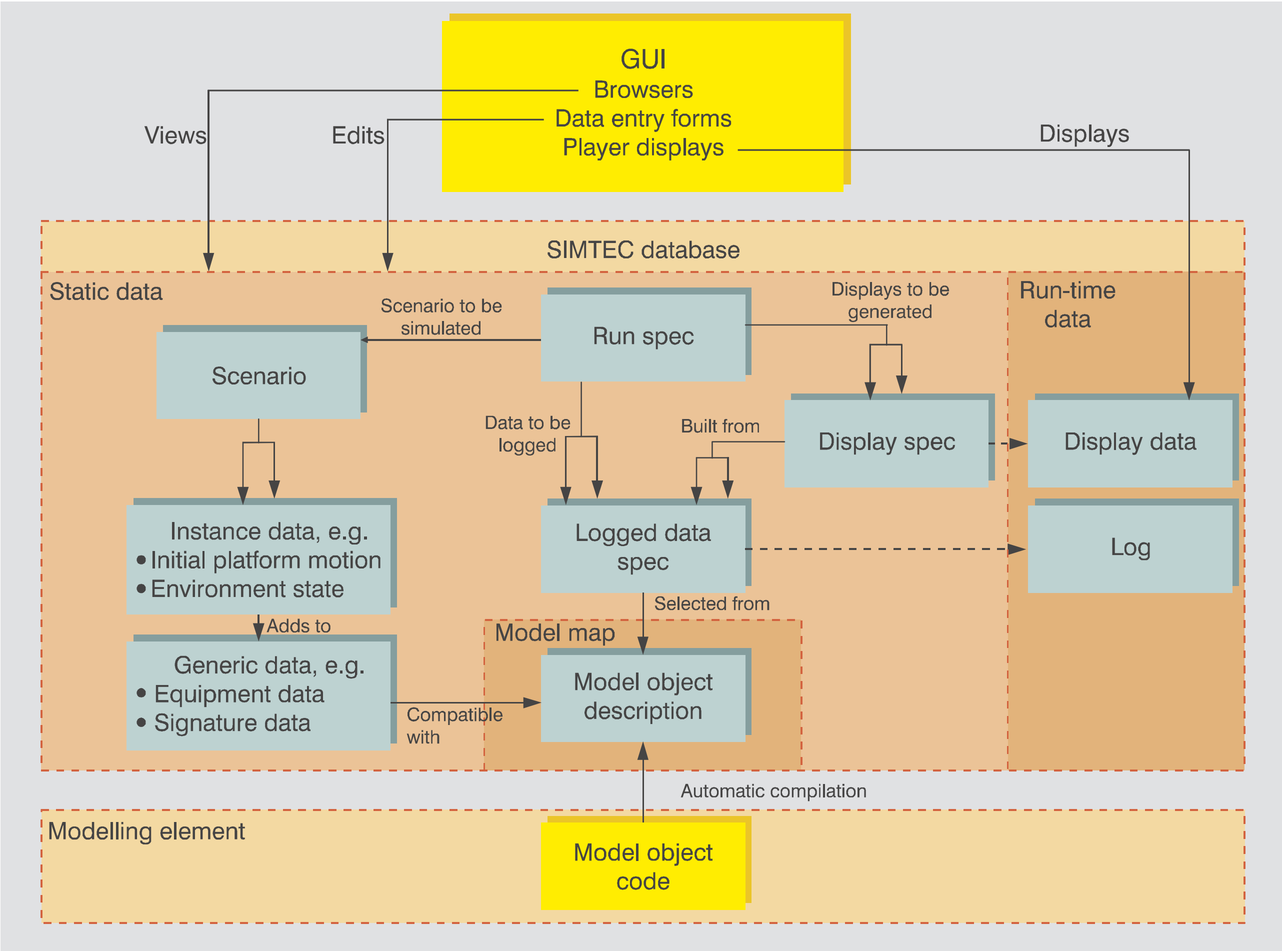
The SIMTEC approach is compared with other techniques, such as the use of Distributed Interactive Simulation (DIS) and High-Level Architecture (HLA) initiatives, that serve to link separately-developed simulations together. It is suggested that, with the right techniques, the use of a single framework, such as SIMTEC, and the DIS/HLA approach are complementary.

Functionality of SIMTEC

The SIMTEC framework is divided into two elements: the 'User Environment' and the 'Modelling'. The User Environment provides an integrated system for defining, executing and analysing simulation runs (implemented by the Modelling Element).

SIMTEC models are highly data configurable and the User Environment supports this approach. As shown in fig. 1, it is based around a central 'SIMTEC Database' that stores:

- definitions of all the 'generic data' needed to construct one or many scenarios – for example, definition of platform components, such as particular types of equipment and electromagnetic signatures, the configuration of these components into complete platform types, and so on;
- the 'instance data' needed for individual scenarios – for example, the environmental parameters, plus the numbers and types of different platforms, together with their initial motions;



1 ***The SIMTEC User Environment***

- the run-parameters – for example, lists of the variables to be logged during a simulation run and a description of whether single or Monte-Carlo runs are to be performed; and
- Player Displays – the User Environment supports simple, but very configurable displays, whose specifications are stored in the SIMTEC Database.

The User Environment supplies a Graphical User Interface (GUI) that provides the above facilities in a windows format consisting of data entry forms, browsers and 2-D / 3-D Player Displays. The User Environment automatically configures itself to the code in the Modelling Element, generating the required database layout plus data entry forms, browsers and displays compatible with this code.

The User Environment performs the automatic configuration by analysing the code of the C++ objects in the Modelling Element to compile a 'Model Map'. This contains data descriptions of all the modelling objects, including the name of each object, a list of its routines and the input/output parameters of those routines. As shown in fig. 1, all the other elements of the User Interface ultimately link to the Model Map, thus permitting the User Environment to be completely generic, yet sensitive to the structure of the code in the Modelling Element.

Within the Modelling Element, SIMTEC provides a sophisticated Battlespace Model representing the arena in which scenarios occur. A terrain database is used to represent both the elevation of the land and the different culture types it consists of, each of which can be described in terms of its backscatter and forward scatter properties. (The sea is considered a particular 'culture' type with a wave structure elevation.) The atmosphere is modelled in the way in which it affects electromagnetic propagation and induces drag, and a variety of atmosphere profiles are available. In addition, weather volumes, such as clouds, and rain belts moving in the atmosphere can be represented. The Battlespace Model is coupled to a powerful, ray-path based representation of electromagnetic propagation, that includes attenuation, reflection, refraction and multipath effects.

The SIMTEC framework currently supports a single (although very powerful) application called the *integrated platform* model. This model is a generalized representation of a military platform consisting of a *superstructure* upon which items of *equipment* can be located and a mechanism for controlling these items of *equipment* so that the platform as a whole behaves in an integrated fashion.

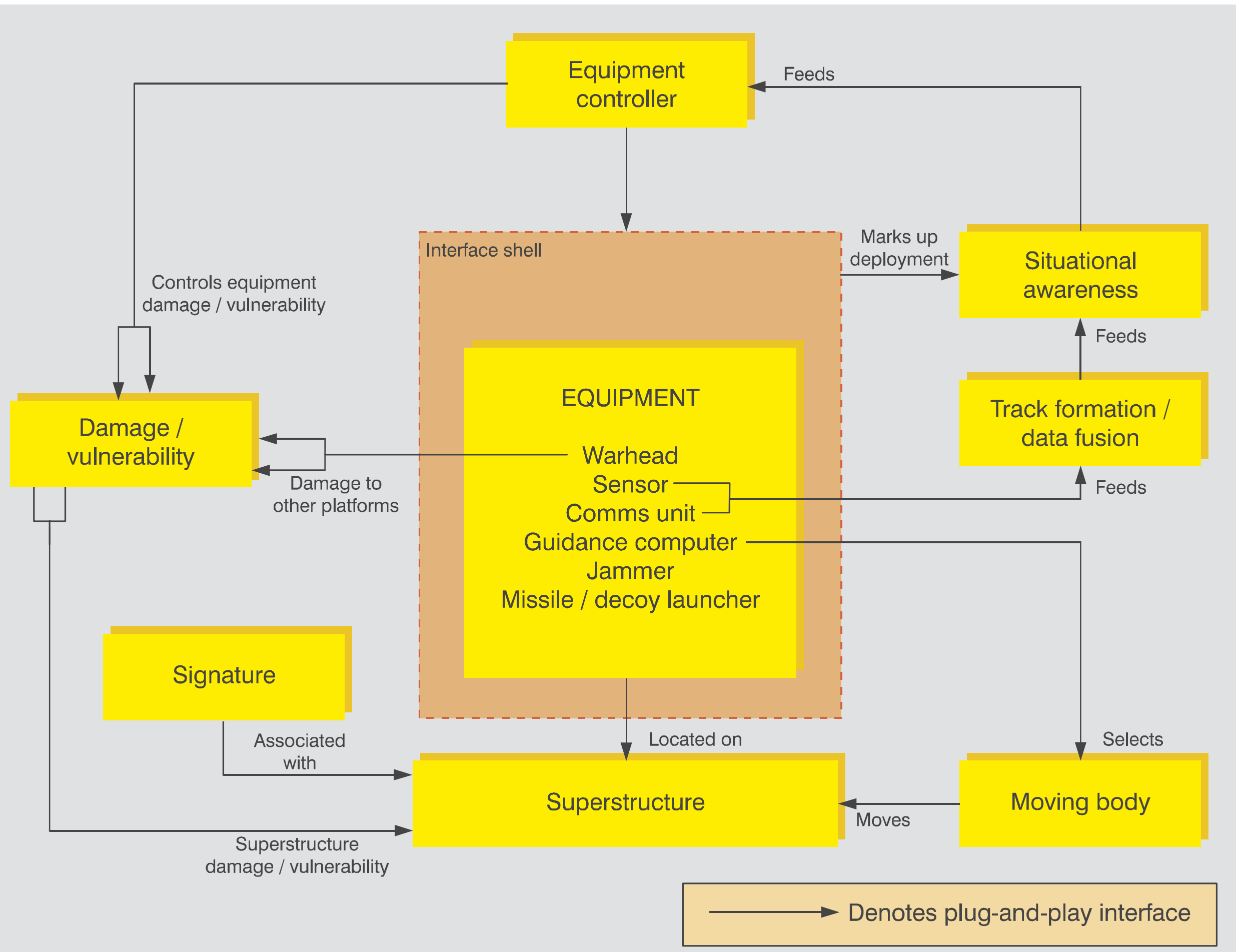
The *integrated platform* model is OO in nature. That is, many different **instances** of the **same** *integrated platform* model can be created at run-time to represent the different platforms, such as ships, aircraft, surface-to-air missile (SAM) units etc., that interact in a simulated battlespace.

In view of the above, the different instances of the *integrated platform* model differ from one another only in their **data**. However, the *integrated platform* model does exhibit a high degree of data configurability in the sense that the **User** (and not the coder) can represent fundamentally different **types** of platform, such as the ships, aircraft and SAMs mentioned above, by defining different data configurations of the common *integrated platform* model.

Thus, to represent a particular scenario, the User sets up generic data sets defining the different types of platform to be studied. One or more sets of instance data are then set-up for each generic data set to define the initial motions of the individual platforms participating in the simulation run. The User can data configure different types of platform because the *integrated platform* has a sophisticated internal architecture consisting of 'components' linked by plug-and-play interfaces.

The architecture of the *integrated platform* model is shown in fig. 2. It consists of a *superstructure* component representing the physical 'shell' of the platform upon which other components can be associated via the supplied plug-and-play interfaces, that is:

- A *signature* component that represents the way in which the platform reflects and radiates energy. A flexible set of *signature* components is provided, including



2 *Architecture of the integrated platform model*

multi-source radar and optical/infra-red representations. One platform can have several *signatures* located on it. A plug-and-play interface allows the location to be defined in terms of a mounting point that gives each *signature* a definite position and orientation (that is – yaw, pitch and roll) offset from the *superstructure* centroid.

- *Kill mechanisms* and *vulnerability* components, which represent the ability of the *superstructure* to inflict damage on other platforms and, in turn, suffer damage. The current suite of components of this type allows both physical impact and explosion interactions to be represented. The supplied plug-and-play interface allows the User to indicate the lethal interactions in which the platform as a whole can participate by associating the appropriate *kill mechanisms* and *vulnerability* components with the superstructure. Another interface allows individual items of equipment to be knocked out or inflict damage (for example, warhead explosion).
- An *equipment* component represents an item of equipment located on the platform. A range of *equipment* components are available, including:
  - *sensors*, for detecting other platforms, which may be radar, electro-optic (EO), infra-red (IR) or electronic support measure (ESM) devices;
  - *weapons systems*, for engaging platforms such as *missile launchers*, *decoy launchers*, *jammers* and *warheads*;
  - *comms units*, for, relaying messages to other (friendly) platforms;
  - *guidance computers*, for controlling the motion of own platform, which can presently manage either predefined – for example, multi-waypoint motion – or implement missile guidance laws, such as proportional navigation or command-to-line-of-sight.
- A plug-and-play interface similar to that used for *signatures* allows equipment components to be located on mounting points.
- Each platform has one *track formation* component and one *situational awareness* component. The *track formation* component takes the output from the *sensor* type *equipments* and use this to form tracks on the targets in the platform's vicinity. In this case, the plug-and-play interface requires that all *sensors* report in a common format. The supplied *track formation* process can also use data fusion to merge *tracks* received from other platforms (via *comms units*). Note that the target *tracks* are sophisticated descriptions holding the perceived positions and motions of the detected targets and the errors in these data plus additional information such as the assumed target classifications, allegiances, emission characteristics etc. The *situational awareness* consists of the target *tracks* marked-up with additional information about the way the platform has deployed its *equipments* against those *tracks* as discussed next.
- *Equipment controller* components exist in one-to-one correspondence with the *equipment* components. Each *equipment controller* operates by deploying the item of *equipment* it manages against one or several *tracks* or (alternatively just switching it on or off). The *equipment controllers* are data configured with rules set up by the User. These rules are based on filtering the *tracks* in the *situational awareness* to determine potential engagements and arranging the *tracks* passing the filter into priority order. The facilities provided to the User in setting these rules are very extensive, so that the filtering and ordering can be performed, based on a large number of criteria. The rules can also take into account the way other *equipments* are deployed, via the mark-ups in the *situational awareness*, so that co-ordinated behaviour can be produced. In addition, timing delays can be added to the *equipment controllers* to represent the latencies in real systems.

Thus, the User can configure a generic data set to define a particular type of platform by specifying its *superstructure*, *signatures* and *equipment* fits and setting up the rules to control its behaviour. It should also be noted that the *integrated platform* model is **recursive** in the sense that munitions deployed by platforms, such as missiles and decoys, can also be described by different data configurations of the *integrated platform* model. Thus, extremely complex scenarios can be simulated in SIMTEC by data configuring the single, generic *integrated platform* model.

Standard Software Reuse Techniques

SIMTEC is an initiative in software reuse. This is achieved by using all of the 'standard' reuse techniques in an integrated fashion (often using innovative technology) that capitalizes on the advantages of each technique whilst minimizing its disadvantages. The 'standard' software reuse techniques employed are:

- library of reusable modules,
- plug-and-play interfaces,
- data configurability, and
- COTS tools.

The idea behind the first technique is to develop a library of software modules that can be used in many different applications. This technique has two great advantages:

- it achieves **fine-grain** reuse – that is, the modules can consists of just a few tens or hundreds of lines; and
- it can be applied to any problem (at least when an OO approach is used).

There are, however, three disadvantages with a library approach:

- it takes power away from the User because it requires a Developer to link together the library modules;
- libraries produced by different vendors are usually mutually incompatible, and the Developer often has to 'buy-in' to one particular library and discard the others; and
- the approach does not guarantee that different models constructed from the same library modules are compatible with one other.

The provision of plug-and-play interfaces has complementary advantages and disadvantages. Its main disadvantages are that:

- it is not universally applicable – that is, plug-and-play works well only when there is some 'natural' division between components existing in the problem space (it is the job of the Developer to find these natural interfaces);
- it usually provides only **coarse grain** reuse – that is, the components it unites are often very large and, indeed, may contain significant areas of overlap; and
- it can introduce inflexibility and overheads (although these problems can be minimized by innovative approaches).

Plug-and-play interfaces do have advantages, however, in that they can:

- permit the products of different vendors to be linked – that is, they can get round the 'buy-in' problem;
- provide the discipline necessary to ensure that models developed from different library components can work together; and
- assist data configurability and the use of COTS. That is, the components linked by the interfaces can be separately configured and/or implemented by COTS packages.

The main advantages of data configurability in its own right is that it:

- puts power in the hands of the User, as opposed to the Developer; and
- it can be much more efficient than hard-coding in tailoring available functionality to applications.

Its chief problems are that:

- the efficiency increase applies only in some circumstances, which must be carefully selected by the Developer; and
- it can also be quite a problem to equip the User with the tools required to perform data configuration in complex applications, although, as will be seen, this is another area where novel approaches can be used.

Perhaps the most direct way of addressing software reuse is to take one particular problem and provide a generic COTS product that solves it once and for all. This is a very good solution if it works, but historically has proved successful only with certain problems that lend themselves to this treatment. Use of COTS can also lead to the problems of 'buy-in' and the functionality of different COTS tools may overlap.

SIMTEC Design Principles Enabling Reuse

SIMTEC uses two main principles – an **OO toolkit approach** and the use of **smart noticeboard** plug-and-play interfaces – to implement the four standard software reuse techniques discussed above. These two principles enable all of the four standard techniques to be implemented in an integrated fashion that capitalizes on the advantages of each technique, whilst minimizing its disadvantages.

The OO paradigm is applied to the **whole** of SIMTEC – that is, the User Environment, the Battlespace Model, the plug-and-play interfaces and the *integrated platform* model application. A 'toolkit' approach to OO is used whereby several rules of good practice are applied to ensure that the objects are (i) small code modules, typically of the order of 100 lines, and (ii) designed as 'servers' so they act like tools in a toolkit in that they offer services to other objects, their 'clients' but are unaware of the nature or structure of those clients.

Application of the toolkit approach causes the whole of SIMTEC to have the form of a large library of small toolkit objects. This is represented in fig. 3 using building blocks to represent the toolkit objects. The toolkit objects fall into a loose hierarchy with objects higher in the hierarchy using the services of ones lower down to build up increasingly sophisticated functionality, represented in fig. 3 by layers of building blocks put one on top of the other. Existing COTS tools are used where applicable to support the toolkit objects.

The OO toolkit approach turns one of the conventional problems with libraries, namely their limited applicability, on its head, because the entire program is a library! However, the other disadvantages, namely the need to 'buy-in' to the library and the problems of model incompatibility remain.

Plug-and-play interfaces are used to get around the incompatibility difficulties. With the toolkit approach, plug-and-play interfaces are implemented by objects like everything else. That is, there is no **structural** difference between the interfaces and the rest of the code. The interfaces exhibit themselves only as **usage patterns** within the interactions between objects – that is, the fact that some objects, the 'interfaces', are choke points in the interaction patterns. This removes one of the potential disadvantages with plug-and-play interfaces, namely their overheads, but does not, by itself, make the interfaces more flexible.

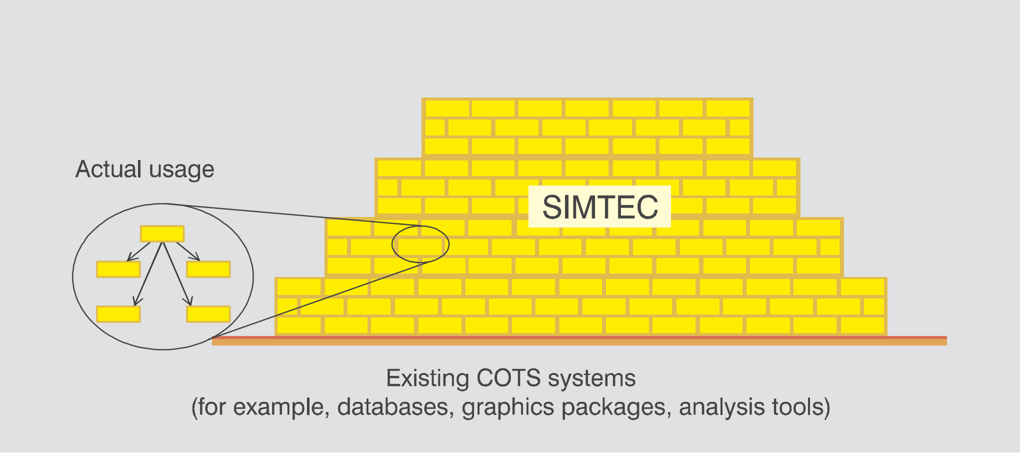
Although similar to any other code structure in SIMTEC, the plug-and-play interfaces are, of course, designed as such by the Developer. In SIMTEC a 'smart noticeboard' design pattern is used to improve the flexibility of the interfaces. This involves:

- making the interfaces globally-visible areas, so they become 'noticeboards'; and
- posting information on the noticeboards as objects – that is, entities with both data and functionality – so the noticeboards become 'smart'.

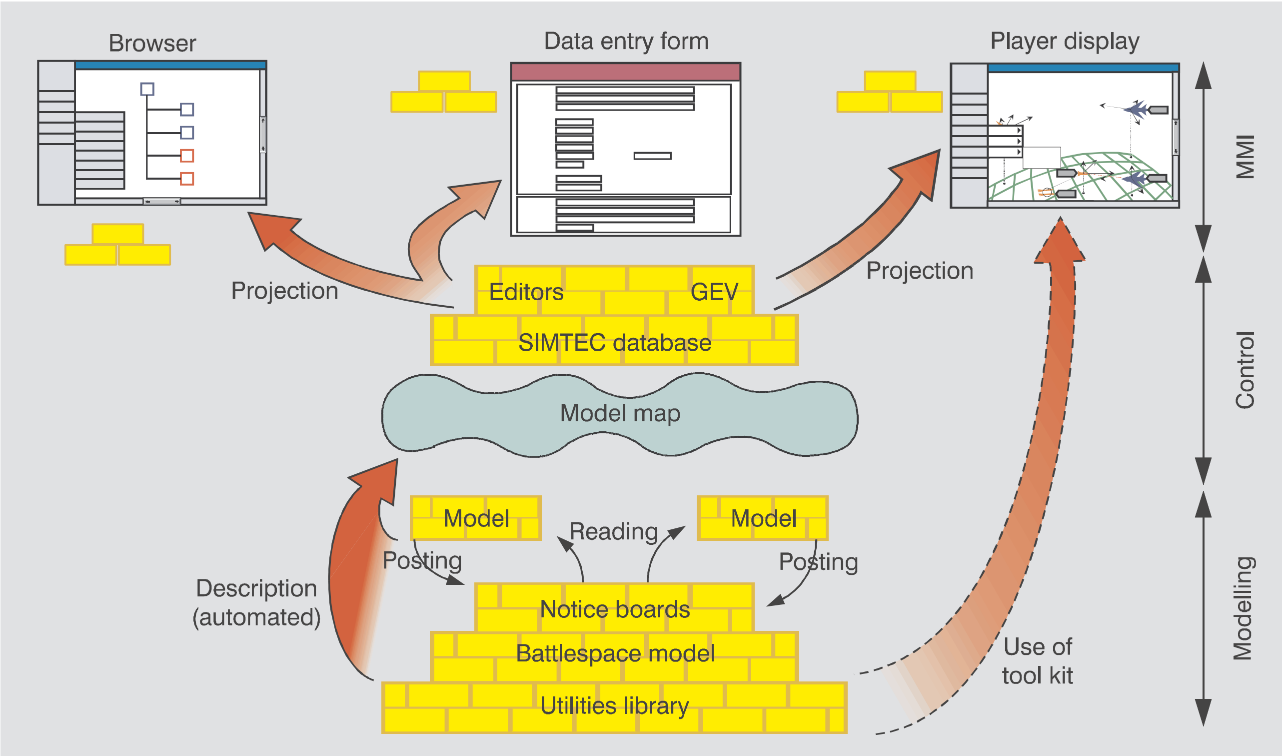
Posting objects on noticeboards improves flexibility because client objects reading the noticeboards can take as much or little of the information as they required (and in fact it is also possible to post multiple descriptions of the same phenomena at different fidelity levels).

Smart noticeboards do not, however, remove the need to choose carefully the areas where plug-and-play interfaces are applied. The interfaces used in SIMTEC are shown in fig. 4 and discussed below.

- Within the User Environment, a 'Projection' interface is used to separate out the functionality, or 'Control' element, from the screen display, or 'MMI' element. Here the information and actions provided by the Control are globally available and are then 'projected' onto the GUI. This has the advantage that as soon as new control functionality is added, in C++, new buttons and/or windows are automatically generated for display.
- The Model Map interface separates the Modelling Element from the User Environment. As previously explained, this map holds a complete data description of all the modelling objects. In addition, however, it also has the functionality to analyse relationships between objects – for



3 ***Library structure of SIMTEC***



4 *Plug-and-play interfaces in SIMTEC*

example, the tree of related objects that comprise the integrated platform model – and invoke routines knowing only the name of the routine and the I/O parameters. This enables the User Environment to execute simulation runs by:

- invoking the necessary routines to set up the battlesapce environment and create all the platforms at the start of the scenario (using the description of the scenario stored in the SIMTEC database as shown in fig. 1);
- running the simulation by driving the event list to advance simulation time; and
- calling the relevant routines to log the data and drive the displays requested by the User.

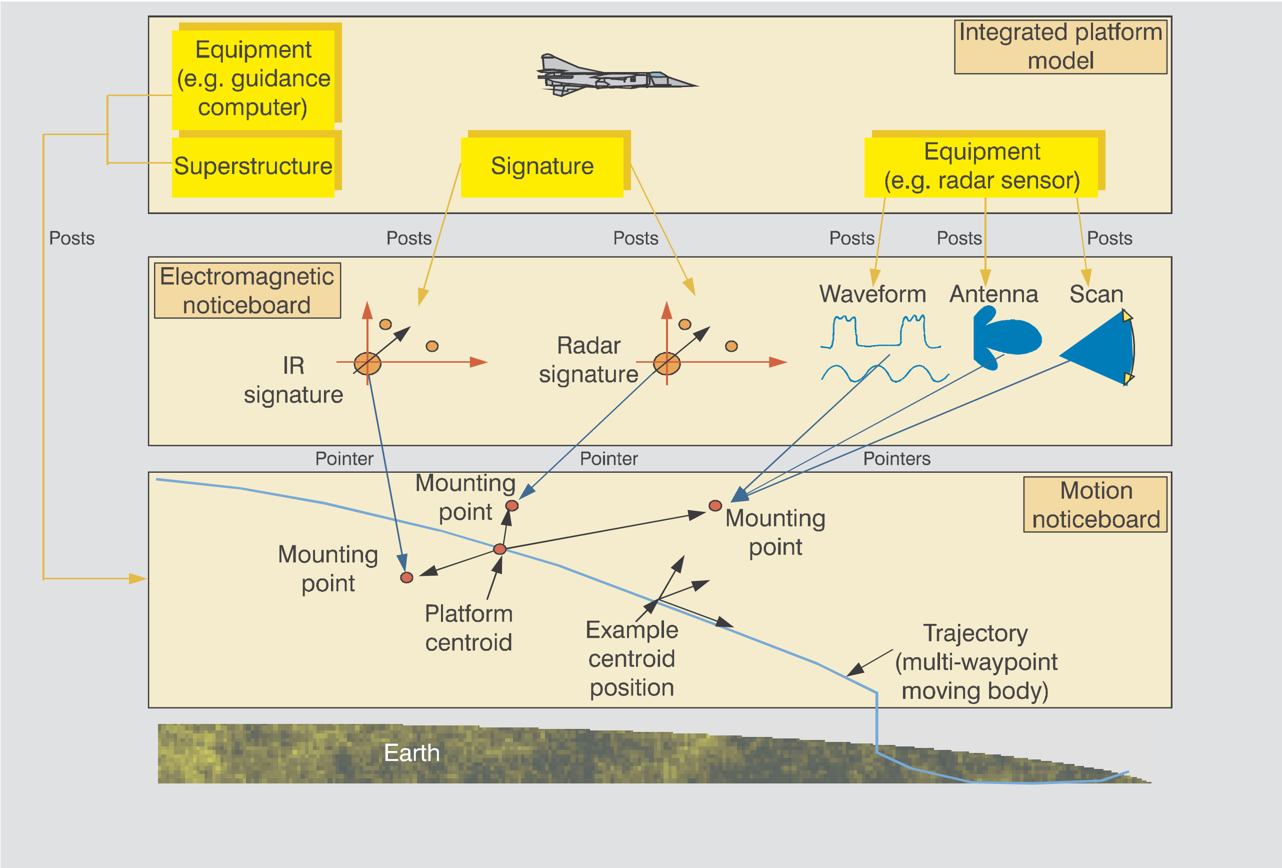
• Within the modelling code, six smart noticeboards are used to handle inter-platform interactions covering:
  - platform motion,
  - electromagnetic interactions,
  - communications,
  - command and control,
  - kills and vulnerabilities, and
  - electronic warfare.

• In addition, smart noticeboards are used to implement the intra-platform plug-and-play interfaces within the integrated platform model application, as discussed earlier and shown in fig. 2.

It is not possible to discuss all the above interfaces in detail in this paper. However, fig. 5 gives an example of two very important cases, namely the way in which motion and electromagnetic interactions between platforms are described.

As shown in fig. 5, a SIMTEC model of a platform, such as the *integrated platform* discussed earlier, posts a description of the motion of the platform centroid as a *moving body* model. This describes motion as a function of time in six degrees of freedom (6 dof) and applies 'until further notice'.

The *moving body* description can be complex and contain discontinuities – for example, a multi-waypoint trajectory with sharp corners as in fig. 5. Because functionality as well as data are posted, however, objects reading the noticeboard (for example, other instances of *integrated platform*) can always obtain exact (6 dof) data at any point in simulation time that they require. In addition, the (6 dof) locations of the platform *mounting points* are also posted on the Motion Noticeboard, so reading objects know the precise position and orientation of all the *signatures* and *equipments* on the platform.



5 *Examples of smart noticeboards*

As shown on fig. 5, some items of equipment can also emit electromagnetic radiation. These emissions are specified by objects describing the emitted waveforms, antenna patterns and scan patterns, all of which are functions of time. Thus, at any point any object reading the inter-platform noticeboards has access to a full description of the factors influencing the electromagnetic signals in the battlespace and can, as required, call up either simple 'cookie cutter' models of detection or access the detailed electromagnetic propagation representations in the supplied Battlespace Model.

Integrated Approach

The use of the toolkit approach and smart noticeboards is integrated with the use of COTS and data configurability so that the benefits of all the software reuse techniques reinforce one another. Existing COTS tools are used where appropriate, but some parts of SIMTEC can themselves be considered COTS products because they provide generic solutions, namely:

- the User Environment, which is completely generic because of its use of the Model Map smart noticeboard; and
- the Battlespace Model (shown in fig. 4), which represents the physical environment in which the interactions on the inter-platform noticeboards occur.

Data configurability is a natural outcome of the OO toolkit approach when coupled with a model-sensitive User Environment.

The way the OO paradigm unites data and functionality means that it possible to data configure **operations**. For example, the 'rules' used in the *integrated platform* models to form priority lists are actually algorithms for filtering and sorting *tracks*. Also, the OO mechanisms of 'inheritance' and 'polymorphism' allow many different objects with different behaviours to have the same interfaces. Thus, the User can choose between alternative behaviour patterns as part of data configuration. The toolkit approach causes the objects available for data configuration to be small and relatively self-contained, thus improving the granularity with which the data configurations can be performed. A model-sensitive User Environment is required, however, to enable the User to access this fine granularity.

Developing SIMTEC Models

Although SIMTEC models are highly data configurable, this does not, of course, obviate the need for code development. It is important to stress that, from the Developer's point of view, SIMTEC is a **clear box** facility designed to produce **fine grain** software reuse and assist the **internal structure** of the models to be produced, as well as providing interfaces to allow different models to interact.

Although the Developer has to write some code from scratch when producing the internal structure of a new model, it will often be the case that much of the required functionality can be obtained from the existing library of toolkit objects. The Developer is free to use these objects as required (that is, SIMTEC is 'clear box'). Also, as all the toolkit objects are small, primitive items of functionality, typically about 100 lines long, they can address the Developer's precise requirements (that is, the reuse is 'fine grain'). The Developer may also construct new toolkit objects that can then be added to the general library.

In addition, provided the new model uses the existing plug-and-play interfaces, it will be able to:

- use the COTS facilities of the SIMTEC framework, such as the User Environment and the Battlespace/propagation models, thus reducing the development effort; and
- interact with all the models produced by other Developers, thereby greatly increasing its usefulness.

In fact, the plug-and-play interfaces can be extended and adapted by Developers and, provided this is done in a controlled fashion, the ability of all models to interact can be maintained.

A pool of SIMTEC Developers is desirable in order to set up a mutually-reinforcing improvement cycle, where each new project contributes new toolkit objects and models and provides the motivation for upgrading the COTS facilities and extending the interfaces. Developers must, however, 'buy in' – that is, commit to using SIMTEC – in order to achieve the benefits of its clear box, fine grain approach.

Other software reuse approaches, such as DIS/HLA, have concentrated on linking together different products via machine and language-independent plug-and-play interfaces. Although this avoids the need to buy-into any one product, it is fundamentally **black box** in nature and therefore produces only **coarse grain** reuse when compared with SIMTEC.

SIMTEC has, in fact, been linked to an experimental model federation via the HLA. It may be, therefore, that fine-grain/buy-in approaches and coarse-grain/linking techniques are complementary. That is, SIMTEC could be used to produce the models that are then linked with other systems via HLA/DIS.

Conclusions

The development of SIMTEC has shown that an extremely high degree of software reuse is possible. This has enabled SIMTEC to support a wide range of modelling applications and provide a completely generic User Environment that is automatically configured to the modelling code.

SIMTEC's software reuse has been achieved by

(i) simultaneously applying several techniques,

(ii) undertaking development on a large enough scale for these techniques to be effective, and

(iii) accepting certain trade-offs.

The paper has identified four main reuse techniques:

- OO toolkit approach,
- plug-and-play interfaces,
- design for data configurability, and
- use and production of COTS tools.

It has been found that a development in excess of 100,000 C++ statements has been required to achieve the full benefits of these techniques.

The major trade-off with the SIMTEC initiative is that fine-grained software reuse – that is, at the individual module level – is possible only if Developers commit, or 'buy-in', to one particular framework. There is little reason to suppose that it will be possible to swop individual modules seamlessly between frameworks any time in the near future.

Initiatives such as HLA and DIS, make different trade-offs. Although they achieve a coarser level of software reuse they avoid the requirement for Developers to buy-in to individual frameworks. This paper has argued that large frameworks that use the right design approaches are complementary to DIS/HLA-type initiatives – that is, frameworks can be used to construct the models linked by DIS and HLA.

For more detailed information on the SIMTEC framework, please contact the author.

Acknowledgements

The author would like to thank Sandy Flett of Weapons Sector, Farnborough for initiating and supporting the SIMTEC project. Thanks are also due to John Witney and Ian Begg of EASAMS; the former for project managing SIMTEC and performing much of its detailed design, and the latter for implementing some of SIMTEC's advanced concepts (such as the Model Map interface) as a practical software solution.

Packaging, Interconnect and the Systems Integrator

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Ever since Intel's Gordon Moore first predicted that transistor integration density was likely to double every 18 months, 'Moore's Law' has proved remarkably prescient, inexorably delivering bigger and faster processors and memory. Intel's 4004, produced in 1971 had 2300 transistors. The 1995 Pentium Pro contained almost 2400 times as many at 5.5 million, with a performance about 4500 times greater. Current predictions are that Moore's Law is good for another decade or two. An accessible retrospective on the electronics scene is given in reference (1).

Over a similar time frame, fibre optics has moved from undersea communications into local area networks and fibre systems and now cable TV. Optical back-planes are now emerging, creating a market for high-performance communications over a distance of a few centimetres.

Against this, developments in electronic packaging appear more prosaic. Whilst the metrics of silicon improvement appear as factors of thousands, the PCB industry would struggle to find a metric that has improved more than a hundred times over the same period and most improvement factors are well below that. Interconnection, it would seem, is destined to be the poor relation of silicon.

However, the relentless pace of change creates problems of its own. Shorter silicon generations have created a situation where chipsets used in the design phase of major programmes are no longer available at the start of the production run – to say nothing of the end of the product's life. A shorter silicon shelf-life, together with other pressures, such as the burden of qualification against the more extreme environments, makes the use of commercial chips for military, aerospace and safety-critical applications highly desirable. Managing the development and deployment of product over a period that represents many generations of its silicon 'innards' is now a major problem born out of silicon's own success.

For the system integrator, this problem is exacerbated: increasingly, the customer expects a long-life system to track the market (benchmarked generally by the PC sector), to benefit from frequent upgrades, face-lifts and even the introduction of modes of operation not conceived of when the purchase was first made. So the obsolescence issue is not merely a case of continuing to maintain performance over a moving foundation, but continuing to deliver state-of-the art performance over a decade or more.

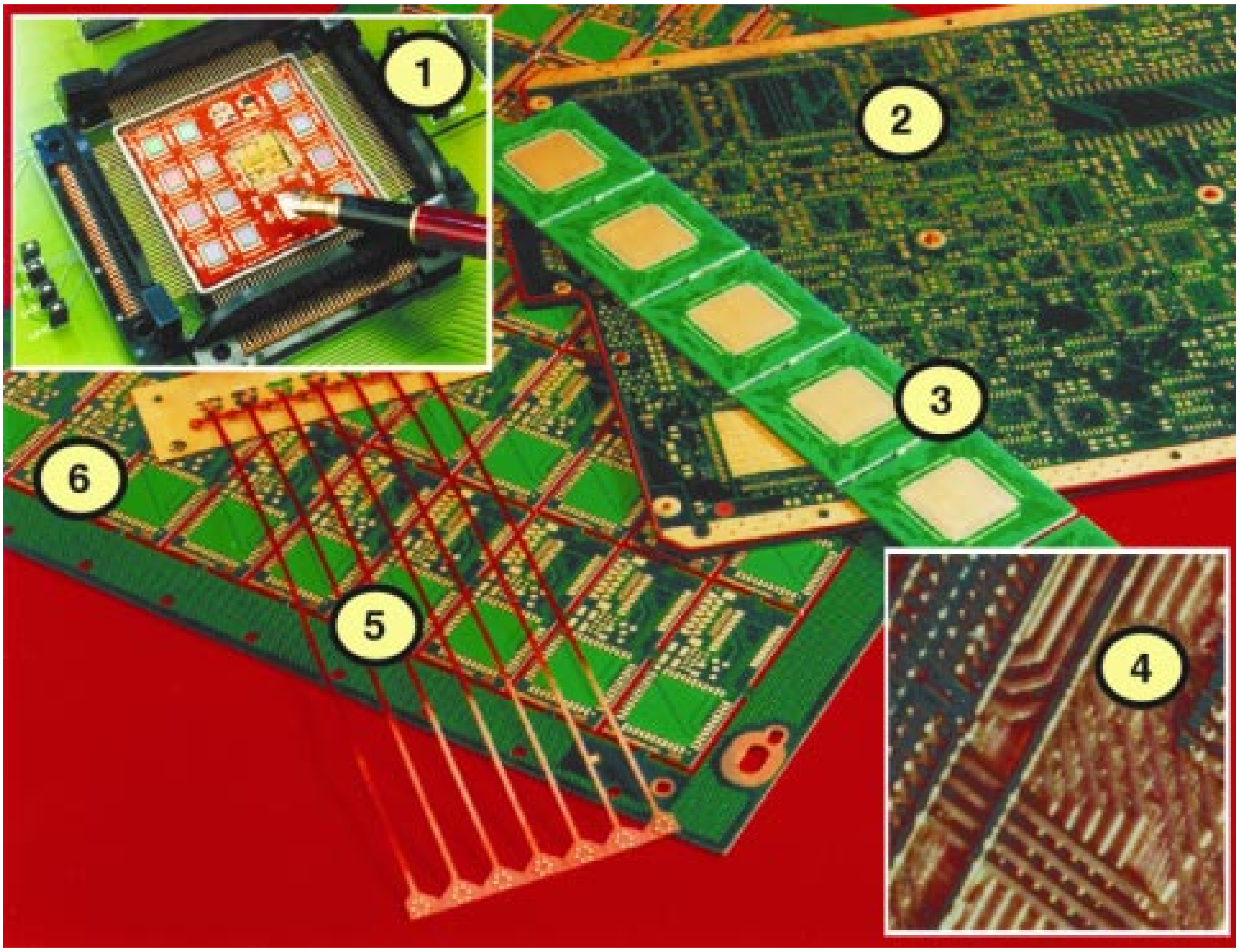
Furthermore, silicon's ability to deliver more functionality within smaller volumes and for less overall power consumption has seen mainframe computing power creep under the desk, onto the desk, into the briefcase and into the pocket. The customer expects that system facilities which are currently fixed infrastructure will become portable and eventually, perhaps, wearable. As the limiting features in systems become the human interface, sensors, connectors or other interconnect, such expectations become harder to realize.

Finally (for the present), this shrinkage means that what was a system has become a subsystem – perhaps even a component. As this happens, the boundary lines change between system elements and amongst the specialist supplier domains from which they come. A shrinking system is one in which the partitions must continuously be redefined. What was a dedicated box, becomes a card in another box, a module on a card, or even a module integrated onto the flexible interconnect between two other parts of the system.

This paper sets out to show that some of these problems, created by the success of silicon, can be solved by advances in packaging technology. As part of an overall strategy, packaging has a central role to play in the war against obsolescence. In the greater battle to manage through-life costs, packaging has a clear contribution to make in providing options to combine the best commercial and bespoke engineering products. Finally, through careful attention to packaging as part of a concurrently-engineered (or holistic) approach, miniaturized systems can continue to emerge and develop.

Having such potential in the present climate, we believe that packaging should occupy a more central role in systems engineering. It should be considered at the outset, rather than at the sunset of the design process. We believe that the time and resources dedicated to addressing packaging issues will more than pay for themselves over the product life cycle.

The advances in packaging and interconnect are well documented elsewhere(2) and this paper is not intended to describe packaging technology itself. For the unfamiliar, fig. 1 shows some of the options. This technology – involving laser drilling techniques, accurate alignment and high-resolution lithography – has produced a generation of boards with track width, separation and vias all around a few thousandths of an inch (50-100μm). At the same time, flip-chip, chip-on-board, and other assembly technologies(3) are increasingly enabling manufacturers to throw away the chip packaging and work straight onto the board. Microwave circuits and even optical fibre can be laminated into boards using processes that are already very close to mainstream manufacturing methods and are eminently amenable to productionization. Together with three-dimensional interconnect and a host of other developments, these advances are having a profound effect in the market for portable products and in the high street. Here we examine the implications for the large system integrator.



1 ***Examples of interconnection options: (1) a multi-chip module, MCM; (2) high-density laminate on heat-conducting core; (3) ball grid array single-chip carriers; (4) detail of high-density interconnect with dielectric etched away; (5) custom chip-on-flexi; and (6) microvia panel***

Obsolescence

Change Management in the High Street

The PC market is remarkable in so many ways that one must take care in looking to it for trends, lest a given trend should turn out to be simply an amalgam of special cases. However, as noted earlier, the PC market conditions our expectations in terms of the pace and management of change. The authors find it remarkable that home and office software developed in the late 1970s will still run on brand-new computers. However, to benefit from two decades of backward compatibility, one would have needed to have bought the right software at the time – no mean feat in view of the variety of computers on offer in that emerging market. It must also be allowed that, for the vast majority, a version of DOS is effectively a legacy management strategy, rather than an operating system of choice. Furthermore, even more recent systems have not maintained anything like strict backward compatibility.

A more subtle, yet useful, and certainly successful form of continuing compatibility lies in recognizing that people seldom need to run exactly the same software, provided that they can continue to access, edit and re-save the files generated using their old software. Thus, an effective change management strategy lies in maintaining (and even developing) a given 'look-and-feel' and providing software filters to legacy files. The idea of several layers to a legacy management strategy is most important.

Of course, it rarely matters if the legacy management is imperfect. Nobody's life is at stake, and the blame for failure generally attaches to the user, rather than the supplier. The situation is very different for the large system integrator, although the concept of multiple levels at which change and legacy may be managed is certain to be central to a successful obsolescence strategy.

Obsolescence Management and Packaging at the Physical Layer

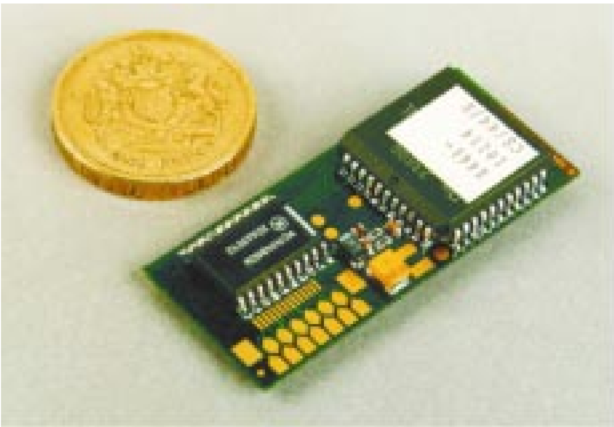
At its simplest, a higher density interconnection medium offers the ability to add function within the original size and weight constraints. Fig. 2 shows a scrambler circuit realized on fineline PCB and designed to fit between the battery and the transmitter of a two-way radio.

This provided enhanced functionality within the original design, eliminating the need to redesign the original radio unit into which it was integrated. Fig. 3 shows a filter bank, designed to fit onto board that had been in service for some time. Again, the performance of the system was enhanced within the constraints of an existing module. Both examples use high-density PCB technology[2,3], both involve a degree of ingenuity to pack the components onto the board. Both deliver new functionality to an existing product and do so without the need to redesign the original system or, indeed, to change the physical layout.

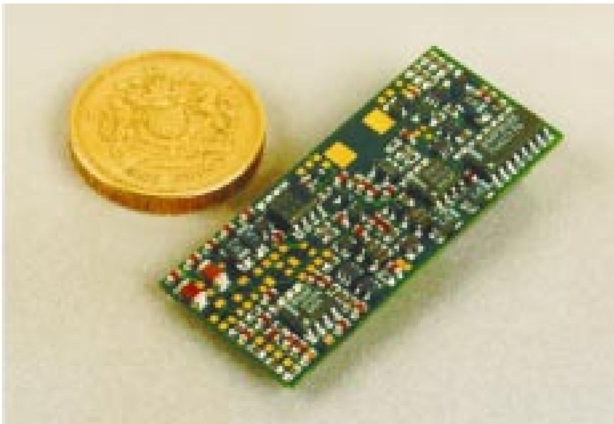
Whilst these examples are intrinsically remedial, involving an R&D exercise after the basic system was built, they indicate a basic way in which advanced interconnect may be used to counter obsolescence.

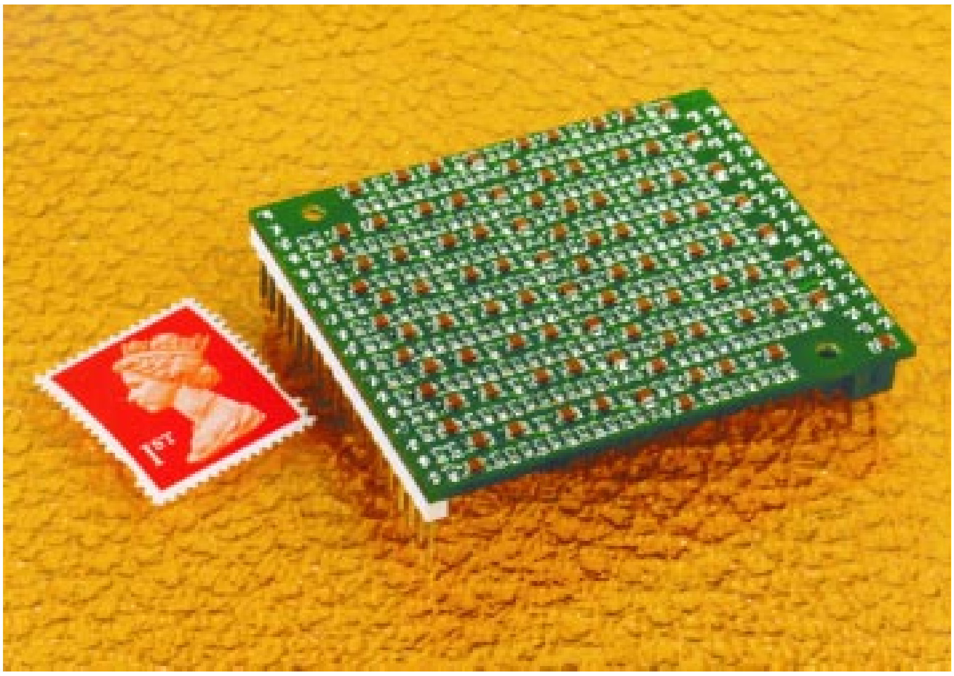
This concept can be developed at the chip level using single-chip carriers (SCCs), as shown in fig. 4. Here a small, high-density, laminated PCB accepts a single chip (such as a processor) on top and provides a ball grid array (BGA) for interconnection onto the main board. In fact, The Marconi Research Centre, Great Baddow (now part of he Marconi Technology Centres), was the first organization in Europe to develop 1mm pitch BGAs. This was as part of a collaborative programme in which it was demonstrated that laminate BGAs are inexpensive enough to displace ceramic as the preferred technology for this type of application.

The SCC or BGA immediately provides a simple barrier against the incoming tide of obsolescence:

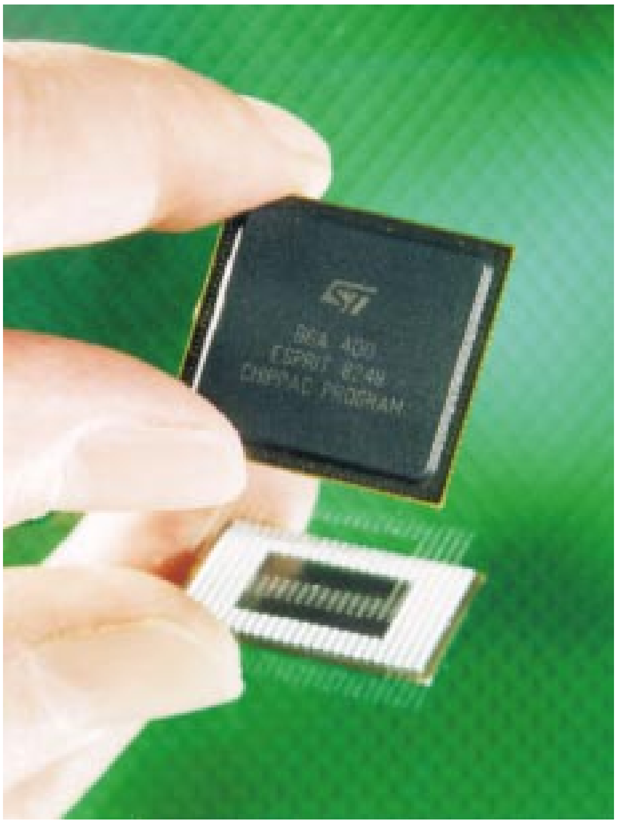


2 ***Scrambler circuit realized on microvia PCB***





3 ***Filter bank upgrade***



4 ***SCC with pentium processor assembled onto it***

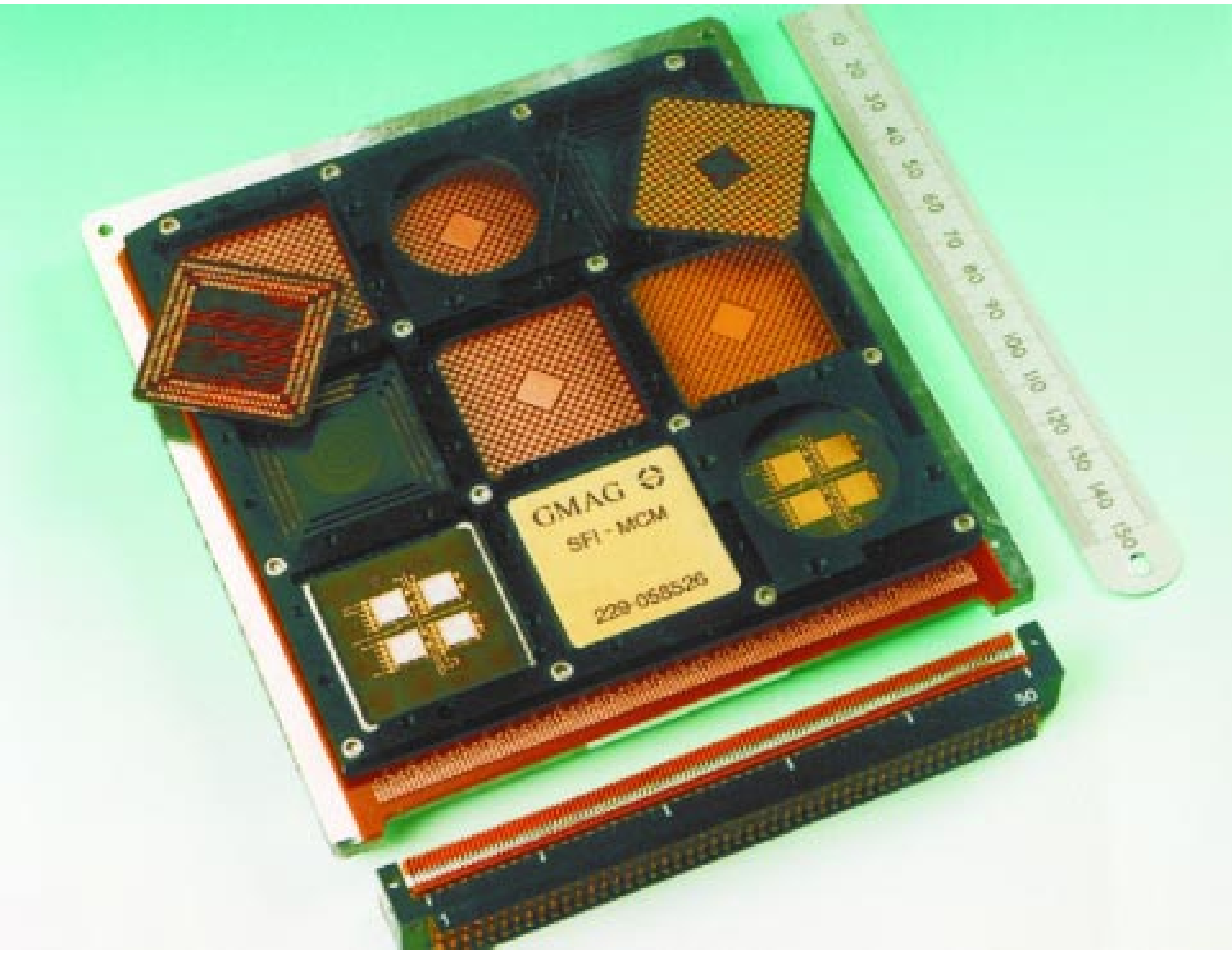
if the higher power successor to the current chip has different pin-outs, the interconnection patterned into the BGA can be modified to restore pin-to-pin compatibility to the board beneath. In fact, given the trend towards increasing processing power and shrinking chips, one could predict, with confidence, that it would always be possible to assemble a circuit above the board to deliver a performance envelope, to the board beneath, that fully embraced the original specification.

This concept can be extended to the multi-chip module, or MCM, in which a few chips, or chips plus passive components, sensors, clocks, etc., can be integrated onto a small substrate that interfaces to the main board through, for instance, a ball grid array. The MCM is a very powerful form of packaging in this context, providing a substrate onto which disparate package types may be integrated within tight size constraints. The small size makes it ideal for high-speed circuits and it offers low tooling costs and short implementation cycles.

Advanced Packaging Concepts for Obsolescence Management

Fig. 5 shows a packaging concept known as solder-free interconnect (SFI). In this concept, a series of multi-chip modules (MCMs) sit on a motherboard. With miniaturization, each module would contain a circuit that might conventionally fill a board. These modules are not soldered into place, however, but are pressure-connected using a variety of micro-connection techniques between the module and the board. Here the interconnect facilitates in-service upgrades, provided typically by a technician with a screwdriver.

Through SFI and other related approaches, one may provide islands of function that can be upgraded. Given the trends in technology, these islands will typically contain a great deal more

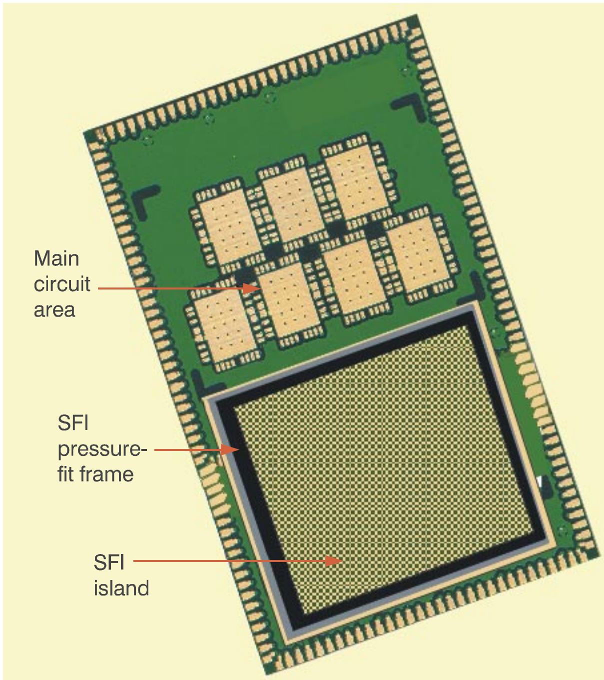


5 ***Solder-free interconnect (SFI) demonstration module***

processing power towards the end of the product life than at the start. It also provides the means to manage these upgrades whilst maintaining full functionality throughout.

Clearly, SFI on its own will not win the war against obsolescence, but in combination with field-programmable gate arrays (FPGAs) and the system software, one has options for managing an evolutionary route forward over many years. It is important to note, however, that the decision on partitioning and packaging must be made as part of the first design on a concurrently-engineered basis, or the whole strategy disappears. Algorithms for partitioning such systems are being developed in collaboration with UK universities.

One need not go for a fully modular design such as that shown on the SFI board: it may be enough to have one or two BGA sites on a board for current or future use in upgrading the board. A pressure connector would have to be developed for isolated SFI modules. Fig. 6 shows what such a board might look like.



6 ***Advanced board with area reserved for SFI***

Cost and COTS

Two attractions of procuring commercial, off-the-shelf (COTS) technology are the cost benefits and the level of choice afforded by commercial markets. In practice, there are several barriers to a straightforward appropriation of COTS technology for military, aerospace and safety-critical applications. These include:

- obsolescence (see earlier section);
- safety, security and confidentiality;
- reliability; and
- ruggedization for harsher environments.

Packaging may have an effect on safety and security issues, but it is rather oblique. It might, for instance, include PCMCIA modules for encryption.

The introduction of COTS systems into harsh environments has been achieved simply by repackaging the outer casing to fit it for the application. However, in other situations, the cost of this hardening undermines the cost savings effected by going COTS. The standard response to this type of problem is to redesign from scratch. Familiarity with the packaging options and control of the technology offers another way forward: repackaged COTS systems. As such, this option is distinct from mechanical repackaging of the outer casing, recasting the system as an ASIC, or redesigning the system from scratch, but using COTS chips.

Repackaged COTS Systems

In the new world of packaging, it may pay specialist suppliers to acquire complete system designs along with proven chipsets and add value by repackaging them for their applications domains. A recurring theme across the hardware and software industry is a redefinition of traditional boundaries: software libraries are routinely leased and used where suppliers would once have produced in-house solutions. ASIC designers use libraries of functions, including complete processors, in order to reach their objectives swiftly and to focus on the aspects of the design and application at which they have chosen to excel.

This concept of repackaged COTS has yet to define the conditions under which it is economically viable – clearly the integration exercise must add more value than the original designer receives in IPR payments, royalties or licence fees. However, it provides a route towards volume and weight savings without prejudicing the integrity of proven functionality.

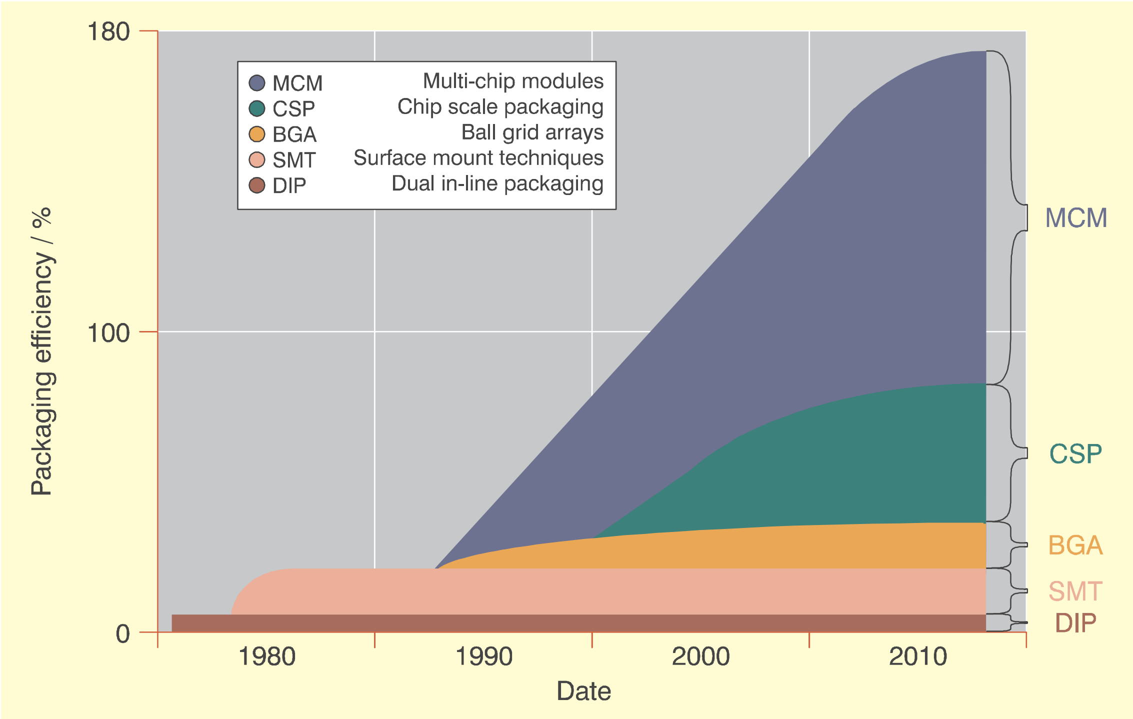
Power savings also accrue, as one can see from the way in which the mobile equipment market uses new packaging technology so extensively. The smaller circuits are, the less interconnect there is to drive and this translates directly into power savings. However, a second effect accelerates the power saving with miniaturization: as more chips reside on a card, the interface chips (line drivers and receivers) simply disappear along with their attendant power drain. This in turn creates more space for more chips. Given the fact that bus interfaces typically occupy 10% of the real estate of a line-replaceable module and may take as much as 25%, this virtuous circle can have a profound effect on the overall power and weight budgets. Some data on the environmental performance of this type of technology is given in reference (4).

Fig. 7 shows the trends in packing efficiency (silicon area/board area) for different types of interconnect. Traditional DIL packages on double-sided PCB are around 2%, whilst MCMs – which can pack silicon in several layers – can exceed 100%. The timeline along the bottom indicates the relevance of these advances to the present discussion.

Clearly, there is a new discipline to emerge in determining how best to take a working product and repackage it so as to maintain the integrity of the original design whilst shedding unwanted power dissipation, volume, mass and susceptibility to mechanical stress and vibration, coupled with ability to manage the thermal problem of high-density electronics. The EMC dimension of this exercise is not a trivial one either, although reductions in size and power consumption generally favour the EMC designer. The system integrator of the future will require a thorough and far-reaching understanding of the packaging technology available.

This links very directly to the earlier discussion on partitioning. For instance, as cards shrink to multi-chip modules (MCMs), interconnected using, say, SFI, the card line-drivers disappear and the bus interface has effectively become the card: the plug-in interface is now a planar interface. In the simple case where this advantage is traded for more performance (that is, more cards of MCMs going into the same box) the partitioning issue is trivial. However, for systems where the card of MCMs is a self-contained subsystem, the ability to package it in planar fashion as part of an interconnect fabric might have a profound impact.

Before leaving this section it is worth noting, then, that the ability to shrink the interconnect and to increase the density of functions redefines the old system partitions. A 'card's worth' of circuitry may typically occupy only 10-20% of the original



7 ***Board fill-factor as a function of technology (key to right-hand column from bottom: dual-in-line packages (DIP), surface mount techniques(SMT), ball grid arrays (BGA), chip-scale packaging (CSP), and multi-chip modules (MCM))***

real estate and so old concepts of how the system is best divided up need drastic revision. However, this repartitioning of systems is a recurring theme in the packaging revolution now underway – not just in terms of what goes on which card, but in terms of what goes on fixed cards and what goes on flexible interconnect; what goes on the substrate supporting a sensor and what is part of the 'real circuit'. These new options create the vision of interconnect as a seamless entity supporting a diversity of functions through different fabrics (laminates, flexis, embedded MCMs, and so forth).

System Partitioning and Integration

Behind this lies a larger debate in terms of the suppliers of functionality. A supplier with an isolated system to sell, complete with its own power supplies, interfaces, built-in test, etc., now discovers that much of that system has been subsumed, through the integration exercise just alluded to, into the bigger system fabric.

The residue of deliverable hardware may no longer represent viable business. Sensor suppliers who have traditionally relied on providing the back-end processing to boost turnover and margins, may discover that the sensor alone is all the system integrator needs, because the integration exercise provides access to ample processing power elsewhere. This trend is not purely a product of advances in packaging and interconnect, but is fuelled by the emergence of open networking, protocols and operating systems. A by-product of the packaging revolution could, in theory, be to move sensor vendors up-system.

The packaging part of the argument, however, may also be made to work in favour of sensor or 'widget' suppliers, because they can now integrate more functionality around their speciality at little extra cost (in terms of currency, consumption or weight). The strategy for survival, however, depends critically on understanding these trade-offs and then pitching in a product with the right amount of processing, the right type of interfaces, the right size, weight and cost, to make it easiest for the customer to integrate into a system-of-systems.

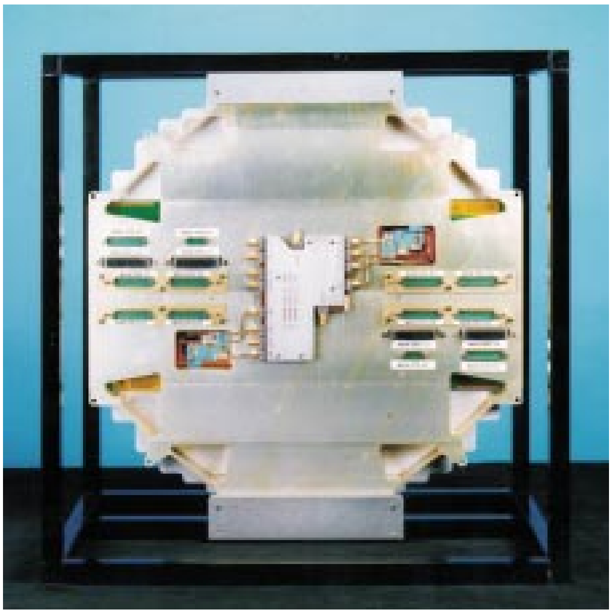
The evolution of TV cameras is an excellent illustration of the way in which system partitioning has changed over the years. People-sized systems with identifiable boxes of electronics have eventually emerged as elegant accessories that lie easily in an open hand. The key to success has not simply involved making everything smaller, but in using the interconnection fabric to integrate fully all the disparate sensors, modules, and peripheral drives, as well as to make best use of the available space.

Assembly of some 'high street' portable products is almost an exercise in origami, as the flexible interconnect is folded up and springs into place on installation. The concept of the 'electronic driver card' or the 'power supply module' is disappearing. The system is engineered as an integrated whole – with all that that means for design, fabrication and assembly.

At the Marconi Technology Centres, Great Baddow we have focused on the development of the fabric to meet a range of requirements. This technology has been available for some time and progress in the commercial market shows how far-sighted some of it has been. Two further developments have also been made in order to support the type of integration required by companies such as Marconi Electronic Systems: microwave circuitry and fibre-in-board.

Microwaves on PCBs

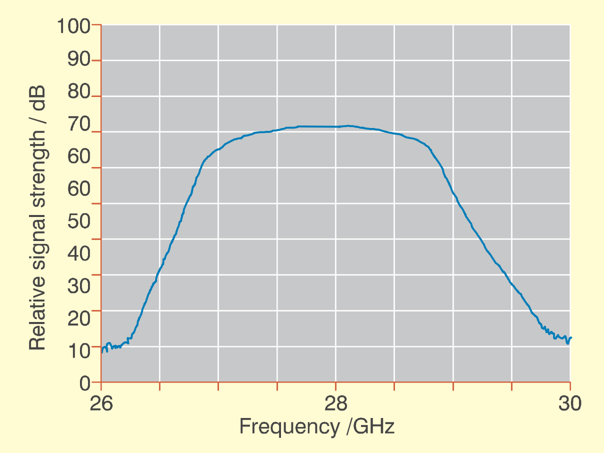
Because the cost of substrates in microwave systems is generally insignificant when compared with the cost of the components, it does not make sense to develop microwave PCBs purely on cost grounds. However, as noted above, there is a great deal to be gained in having a common medium that will embrace all aspects of the system. Fig. 8 shows a 10GHz signal distribution manifold, built for a radar application, which uses laminate, or softboard, PCB technology. This demonstrator has tackled such areas as wideband right-angle transitions and 1000-way microwave splitting, whilst maintaining the dimensional tolerances needed for an active antenna array. The structure contains multi-layer, screened, digital signal distribution in polyimide glass with stripline active networks and buried passive components in multi-layer PTFE on an aluminium carrier.



8 ***10GHz distribution system on softboard***

Fig. 9 shows a fibre-fed communications modules designed to perform the final drop (for example, lamp-post to the home) for interactive ATM services on RF carriers between 27GHz and 30GHz. The microwave filters and patch antenna arrays have been fabricated on softboard. Fig. 10 gives a typical response of the filters. The tolerance required here is 5% on dimension of <50μm. As a stand-alone substrate, this technology will have competitors; as a microwave circuit on a seamless fabric embracing an integrated system, it is unique.

9 ***Communications unit providing a radio interface to a fibre network***

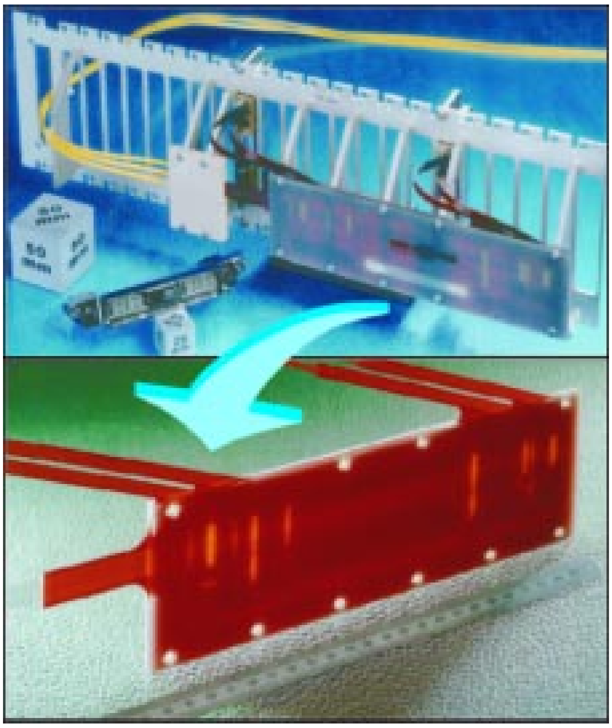


10 *Response of a softboard filter*

Fibre-in-board

Another development has been in support of closer integration of electronic and optical integration. Fig. 11 shows an experimental structure in which fibre is embedded in one of the laminate layers that would typically serve as the dielectric separators between metallization layers. The technology has already been developed as an avionics backplane(5) and is currently under development for telecoms applications.

The benefits in terms of fibre management are important. The technology introduces fibre backplanes into systems in an evolutionary, rather than a revolutionary manner, which is also important. However, the key advantage from a systems



11 *Laminated fibre-in-board (bottom) and backplane embodiment (top)*

viewpoint is that both optics and electronics can be integrated onto a common substrate. Whether the unit be a high-functionality module (such as a fully-integrated true-time-delay subsystem for a multifunctional radar) or part of the system infrastructure (for example, a high-speed, EMC-immune, backplane for a supercomputer), the system designer has access to both optical and electrical interconnect in a common medium.

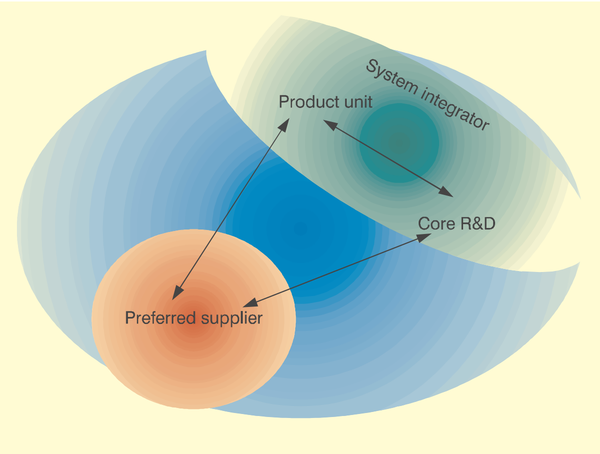
Who Pays?

The key question here is, 'who benefits?'. In this paper, we have argued that the most significant benefits are achieved by addressing packaging earlier rather than later – in design, rather than in production. Furthermore, we have argued that the biggest benefits accrue in terms of life cycle costs, rather than purchase price; in system integration, rather than product manufacture. For these reasons, we believe that packaging is primarily a systems issue. The team at the Marconi Technology Centres, Great Baddow has pioneered advances in packaging and interconnect for the past fifteen years for precisely this reason.

Many would argue, however, that the board manufacturers are making the money from the technology and should therefore fund the R&D investment. Sage(6) argues cogently in this respect that the source of innovation funding depends on the state of the interconnect cycle. Where evolutionary change is underway, it lies with the board manufacturers – and particularly their suppliers – to squeeze new performance out of the existing product and to offer better value to the system customer.

However, in the process of revolutionary change, the board manufacturers, with their tight margins are unlikely to invest in new types of equipment without a clear view of the applications and volumes. The system integrator has exactly this insight and therefore the most to gain. At times of revolutionary change, system integrators must, then, support the changes. The current state of flux in packaging clearly lies on the revolutionary rather than the evolutionary side of that divide.

However, other factors must also be considered, especially because many large systems houses have dispensed with their traditional in-house manufacturing. They are thus dependent on subcontracted support and yet are being asked for financial support towards the sea-change in packaging needed to maintain competitiveness. Recent analysis of the supplier market(7) indicates that two types of board supplier will survive in future: the small contractor and the large conglomerate. The former will survive because of its fast turnaround and ability to provide a high-quality,



12 ***Interaction between a systems company and an interconnect supplier***

versatile service. The premium this service attracts compensates for the less competitive aspects of low-volume production. The mass producer (£100 million+ p.a.) will continue to grow because it can afford the capital investment and benefits from massive economies of scale. According to this analysis, everyone in between will be squeezed out and the big will continue to get bigger.

We believe the role of a system integrator in such a scenario is to maintain a leading-edge R&D team and to form preferred supplier relationships with one or more candidates from the two categories outlined above. This type of arrangement is shown in fig. 12 and frees the system manufacturer from the capital outlay involved in maintaining its own production, provides it with a vital degree of foresight in the field, and ensures, through technology transfer, that the right technologies are there in production when required. The flow of cash and intellectual property rights (IPR) involved in reaching such an agreement is beyond the brief of a paper such as this.

Conclusions

Conventional system design has placed packaging (that is, the technology that will be used to produce the final product) low on the list of priorities and late in the design process. We believe that packaging is more beneficially considered as part of the initial design. In particular, as part of an integrated design strategy, packaging delivers vital benefits in three areas: obsolescence, access to COTS, and in integrating the next generation of systems.

Appropriate packaging provides a response to obsolescence at the physical level where BGAs and MCMs can be used to ensure that a consistent function is delivered to the motherboard, despite changes in the silicon above the interface. At the more advanced level and in conjunction with FPGAs and the software design, it should be possible to ensure that the functional envelope of an evolving system embraces fully the original requirement and that upgrades are introduced in a controlled and manageable manner. That this is possible is evident, but R&D is needed to understand completely the impact of using such a strategy.

As far as COTS is concerned, advanced packaging can provide a route between wholesale use of COTS and bespoke systems. By repackaging COTS, one has opportunity to reap the benefits of proven systems whilst providing the right environmental capability for a given application.

Finally, integrated miniature systems are forced to rely on an increasingly complex array of integration technologies in order to bring silicon chips, sensors, interfaces and peripherals together. The Marconi Technology Centres, Great Baddow, has supported this drive by integrating technology for microwaves and optics into the basic PCB laminate processes.

Overall, packaging is a weapon in the system integrator's armoury. Various levels of systems edge can be obtained by appropriate deployment of the technology. In particular, teaming arrangements with the most competitive suppliers should enable the benefits of leading-edge R&D to be fed through in support of advanced systems that, in turn, will be better future-proofed and able to deliver improved performance over their life cycle.

Acknowledgements

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From the GEC Archives...

The History of the General Electric Company up to 1900 – Part 1

by H. HIRST, M.I.E.E.
Chairman of the GEC 1910-1943

During 1920, Hugo Hirst gave a series of lectures to the GEC Debating Society, of which he was Chairman at that time. During these talks he described the events that took place during the five years leading up to the formation of the General Electric Company in 1886, through to the year 1900. These lectures were recorded in shorthand and subsequently transcribed into typescript. The final version, with annotation by Hirst himself, now resides in the GEC Archive collection. In this paper, which is divided between successive issues of GEC Review, we present selected extracts from these lectures, some 100 years after the events which he described took place. We have reproduced the original text without amendment, except in the instance of obvious typographical errors, and have illustrated the extracts with photographs and drawings from other publications contained in the GEC Archives.

I have often been asked to write the history of the G.E.C., but I am still too busy to grant myself the time that such work would require. I have, however, fallen a victim to many entreaties to try some evening to give you that history.

I have been thinking over how such a task could be fulfilled without wearying you and yet be useful. I do not know exactly at this moment how to treat the subject, but one thing I am certain is it cannot be done adequately in so short a time as is allowed and is usual and desirable at a meeting of a Debating Society. I also wish to make it quite clear that I am not here to give a story of my life. My life must necessarily play an important part in the development of the General Electric Company because the two things have been so interwoven; therefore if I speak much of myself I do not want it to be misunderstood.

The G.E.C. is not the work of one man; the G.E.C. is the work of many people from its earliest days onwards, and I can only describe it as I saw it at any time, I can only give you the impressions such as I have experienced from time to time, and if

H. Hirst, first Baron Hirst of Witton, was born in Munich in 1863 and came to England when he was 16 to build up a career which made him a leader in the electrical industry. It was at the age of 19 that he entered the electrical industry, but it was not until 1886 when he joined Mr. G. Byng in a little electrical shop in Queen Victoria Street London EC4 that his life's work can really be said to have begun, for this business was the seed from which sprang the G.E.C. He became Managing Director of the Company in 1900 and Chairman in 1910. Lord Hirst was one of the first to realise the importance of research in industry, and the Company's research laboratories are among the leading industrial laboratories in the world. A recognised authority on international trading, he served as Economic Adviser to the Cabinet Research Committee and on many committees, such as the Cabinet Trade and Employment Panel, Advisory Committee of the Board of Trade 1922–25, 1929–32, 1936–39, as well as the Committee on Unemployment Insurance 1925–26, and the Committee on Co-operative Selling in the Coal Industry 1926. In addition he was a member of the Melchett-Turner Conference and also served on the Committee of Industrial Research. He was also a member of a number of industrial and research institutions connected with the electrical and its allied industries. For the two years 1936–38 Lord Hirst was President of the Federation of British Industries, having formerly acted for some years as chairman of the Empire Committee of that body. He was President of the Radio Manufacturers' Association from 1938, hon. member of the Institute of Electrical Engineers, past president of the Association of Technical Institutions, and a past president and one of the founders of the Institute of Fuel. Further, he was a past president of the British Export Society and the British Electrical Development Association, as well as the Incorporated Society of British Advertisers and the Decimal Association. He was Master of the Glaziers Company for two years from 1928–1930. A baronetcy was conferred upon him in 1925 and he was raised to the peerage in 1934. He died, after a short illness, at his home, Fox Hill, Earley, Reading, on January 22 1943 at the age of 79.

(From the Financial Times, January 24th 1943)

therefore I omit the names of some who have collaborated it is not from any selfish motive, or trying to take glory where it is not deserved, it is simply because in reviewing a long period of 35 years without having prepared any notes it is impossible to do justice to everybody.

I intend to give you this history of the G.E.C. with an object. It is my intention as I wander through the many years to endeavour to describe the condition of the time so that you will better understand the risks which one ran and the reasons why one did certain things or did not do certain other things; and if I succeed in that I hope that this address or lecture, or I might even venture to foreshadow a series of lectures, will be instructive as well as interesting.

The Early Days

In order to give the history of the G.E.C., I must introduce my humble self through the few years preceding the actual starting of the G.E.C. I think my experiences during the years from 1881 to 1883 and from 1883 to 1886, the actual starting of the G.E.C., were very largely contributory to the character which the G.E.C. in due course assumed; it was a creation entirely different from any other electrical concern when we started it, largely on my suggestion, in 1886. There were no central [generating] stations; there was no general electric supply; there were makers of dynamos and makers of submarine cables who first started to make some rubber coils to suit the dynamo makers. Many a time a dynamo was run for months before lamps could be supplied or shades put on the lamps; and the idea of the G.E.C. when it was started was to make it a supply business for the benefit of contractors and installers. Our speciality was to study what all these different people used so as to be able to tell them:

'We have it in stock; you need not delay your installation; we keep everything in stock'.

We were laughed at at the time as being an electrical business which did not do any installing, but in course of time the usefulness of the idea was appreciated and supported, and we had imitators in this and every other country.

These few words should tell you that the G.E.C., when it was started was originally looked upon as a quaint effort of some outsiders who did not know what electrical engineering was.

With these introductory remarks I would like to refer to the few years preceding my own experience in connection with it when I met people who collaborated and were instrumental in the starting of the G.E.C.

In 1881 I was appointed as private secretary to the Managing Director of the then new Electrical Power Storage Company. It had been only quite recently incorporated, I think with Pritchetts and Gould, which Company, with the exception of the vicissitude I will refer to presently, led an honourable life for 20 years. That Company had the patents for accumulators. That was during the period when all electrical invention seemed to be made. Mr. Edison had just invented his carbon lamp, and Mr. Swan had simultaneously invented the Swan lamp; the Jablakoff candle was shown off on the Thames Embankment, and other arc lamp makers appeared in the world with new inventions. Arc lamps were in those days driven by clockwork; they allowed the positive and negative carbon to move at a fairly equal speed, and the makers tried to calculate out the speed equivalent to the burning capacity of the carbon; with the unreliability of the carbon you can imagine how these lamps burnt and what flickering and what other effects took place to make arc lighting an impossibility.

Dynamos were in those days very unreliable things. The so-called Siemens dynamo which shewed in the incandescent lamp supplied by it a flicker every time the belt passed a certain position was at that time the best machine. The invention, therefore, of accumulators seemed in those days the ideal thing for the electric light: you could charge accumulators during the day, took your current from the accumulators during the night, and you would have a steady light. Well, I know a little of what I stepped into. I used to write articles for newspapers which may inform Mr. Palmer that my connection with the Press (and you know what the Press is capable of) dates back to 1882. We used to boom the possibilities of accumulators. We sold patents to Russia for £184000 (sums of which I did not appreciate in those days), and we sold patents to every other Country, but I never saw money, I only saw stocks and shares. We carried on installations for which we were never paid. We fitted up the Grand Hotel, but it was not my managing. I stood aghast and looked at the proceedings. We fitted up the 'Gaiety' [theatre] for no payment but simply to have the advertisement of what the accumulators could do; and the usual phrase in those days was 'Electricity will be carted around to the houses every morning with the milk'. That was the common idea. It may seem strange to you, but the public knew nothing about electricity. I have seen letters which customers sent me which said:

'We have bought your lamps and we have used a whole box of matches and cannot get the blooming thing to light'.

When wires were supplied, which was in later years (I only mention this to show the absolute ignorance of the public) we sent a quantity of wire to a ship and wrote mentioning the quantity and insulation resistance, and the ship sent it back saying:

'insulation resistance not contained in case'.

These are facts which I mention not merely for amusement but to give you a sort of idea what the mind of the public was. They believed in those days that accumulators were going to be sent round with the milk, and paid the consequences for it.

I had not very much to do. The most important event of the week occurred on Tuesday, when the Directors attended the Board Meeting. There was champagne, port, and sandwiches of every kind; they never touched them, but I had a cheap meal that day.

I had a very strategic office chair. My seat was at the end of the office, so when the manager came out of his office he always saw me. That was an indirect advantage; every man who came in saw me first, and, as I had nothing to do, I tried to answer questions; it was in those days I made the acquaintance of Professor Sylvanus Thompson, of Lord Kelvin, of Sir William Preece [the Engineer-in-Chief of the British Post Office], Mr. Houghton of the Brighton Railway, and others. In other words, as there was no organisation for selling and nobody cared exactly what happened in business so long as these jobs were carried on, the callers applied to me, and as I was willing to oblige I became so to speak, their instrument in communicating to the powers that be everything they wanted. I did my best. They appreciated my efforts and it was certainly useful in my later schemes to have made the personal acquaintance of these men when I started in actual business; and it was of tremendous use that humility, that desire to oblige, that desire to help the customer, though it was not my duty; and I emphasise it as an example to some of the younger men in our firm today who might be induced to think that anything that is not their own job is not worth while looking after if it comes in their way.

The Manchester Gas Lighting Company

After about two years of a variety of very hard, busy work I had nothing to do; the inevitable fate reached the Power Storage Company, and it had to go into liquidation to reduce its capital. Well I got

1 ***Mr Gustav Byng (circa 1900)***

the sack. I had to do like so many other people, look out for a job, and I heard that a Company from which Mr. [Gustav] Byng (fig. 1) was purchasing certain goods was looking out for a man to go out to Australia; it was the Manchester Gas Lighting Company, who invented the gas lighter, the first actual speciality of the G.E.C. That Company wanted somebody to go to Australia. They were making gas lighters, electric bells, and medical coils, and I applied for the job and with Mr. Byng's help, I got it.

While I was with the Electrical Power Storage Company I lived privately with Mr. Max Byng who was very ill for a good many months. I used to go round every luncheon hour between 12 and 2 – I stretched it – because I had very little to do in those days; and also after my office hours, which meant five minutes or five and a half minutes after the Managing Director left, I did all the business of Mr. Max Byng – entered his books, made out the invoices, and whatever was necessary, sometimes 'til 10 or 11, and out of gratitude he helped me to find a job. I accepted the situation; I was very keen on going to Australia, I thought I would make my fortune. I went home to say goodbye to my people, and came back equipped with revolvers and boots, and all kinds of things that relations give you, and on the way back I met one of the best, Mr. Falk, who is now dead. He asked me: "what are you doing here?" I told him, in high glee, what I was about to do; he said: "I thought you were a clever fellow; you are a 'd' fool". I said: "Why?" He said: "Either electricity is going to be something or it is going to be nothing; if it is going to be something there will be more electricity within four miles of Charing Cross than in the whole of Australia; therefore, if you stick to electricity stick to it near Charing Cross".

He was about nine years older than myself and was in the gas business and looked upon electricity with a sort of sneering sentiment. I was not of age yet and was really sent over to my father to get a guarantee. I never had any money from my father in my struggles – I refused to take it, but the Manchester Company wanted a guarantee that I should not do a bolt with the stuff they entrusted me with. Those words of Mr. Falk sank in. I went home, and before I had shaved that evening I had made up my mind, "I am not going to Australia". The Directors did not like it, they even threatened a bit; and then a stroke of luck came my way – it was in 1884 – and in the Press notices appeared of a Bank smash, and things were bad in Australia. There was a great crisis in 1884; the firm thought it would be foolish to send me out there, and decided to use the stock by opening retail businesses; they opened a place at No. 58 Queen Victoria Street and one at 4 Charing Cross. Mr. Max Byng managed the Charing Cross branch and I managed the Queen Victoria Street one.

That is where the second chapter started. It is essential I should go through that before I come to 1886, the real beginning. In that shop we tried to sell the produce of the Manchester Company, which, as I said before, was gas lighters. There were two kinds of gas lighters. First there was a battery with chloride of silver, and there was a stem in which the conductor went up, and there was a little hole in the top in which the spark shewed itself; you turned on the gas and the electric spark ignited it. That seemed a little thing, but it meant a lot of business received through the assistance of the Insurance Companies because, in the cotton factories where they used gas, so many fires originated through the throwing away of matches that if the mills shewed they used only electric gas lighters, they received a rebate on the insurance. That was the only business that Company had, the rest was medical coils and accumulators and scarf pins; and in order to show them off we had to have a gas engine in the basement.

It may sound funny, but it was simply awful in those days to be a shopkeeper. I lived in St. John's Blackheath; I enjoyed a great local position in the Swimming Club and Tennis Club, and amateur theatricals, and was invited to dances; but if anybody had known I was a shop-keeper I am afraid I would have been ostracised from St. John's. I wanted to look as respectable as possible, and the cleaning of the shop, and the cleaning of the engine, the starting of the engine, and the arranging of the shop window, was a very serious thing which I did before office hours, before the ladies and gentlemen of St. John's came into London. Many a time I caught the train at 6 o'clock in the morning in order to look a gentleman by 9.15. It did not do me any harm; I only mention it to shew how one had to work in those days and how useful the work was. One obtained experience which enabled one later on in organising this Company to know what to expect from each man. My salary was £2 a week and a bonus on the profits, if any. Well here again it was the only electrical shop in the City, and every man who took an interest in electrical affairs strolled in, if only after lunch in order to have a chat. A number of people invaluable to me in after life such as engineers, and medical men, even, came in.

Partnership with Messrs Byng: the General Electric Apparatus Company

Mr. [G.] Byng did not get on with the Directors of the Company and he parted from them and he wanted me to join him. I accepted Mr. Byng's invitation and went to a new place he had taken, No. 5 Gt. St. Thomas Apostle (fig. 2). He had his brother [Max] with him (fig. 3), and there was another man who was his manager, named Lawrence.

I then joined with Mr. Byng in a separate department, and all the help I got was an office with absolutely nothing in it. I did nothing for the first week or two but go round to all the engineering firms telling them I wanted to start a depot supply department,and what were the things they wanted.

The Catalogue: a Commercial Innovation

Then I sat down and realised that if you wanted to develop, a catalogue was essential; and I very much recommend to your inspection a catalogue which was published in 1887. I joined on the 16th September, 1886, and there you have a catalogue that must have taken 12 months to prepare, though it was my first. If you look through it today you see that I unconsciously had the idea of the G.E.C. in mind. It was my department, called 'H' Department. I start with a switch board; then come a series of small switches; then some ceiling roses, cut-outs, etc. I made a trip to Germany before that catalogue was finished, and you find glass ware.

2 ***5, Gt. St. Thomas Apostle, London – the first premises of The General Electric Company – shown, as it is today, in the centre of the photograph***

We wanted everything electric, and I got an agency for carbons, and then I had dynamos and finished up with engines. That was published in 1889, and except that each article may be today a Department, and we manufacture the things, that is the idea of our catalogue. That is the first catalogue of its kind, in this or any other country, which was ever attempted, and that is why I make this the introduction of the years that preceded 1886 in order to show how I arrived at the idea. Of course, it might not have worked, and then I would have had to switch over to something else, but the idea proved the right one and we went on.

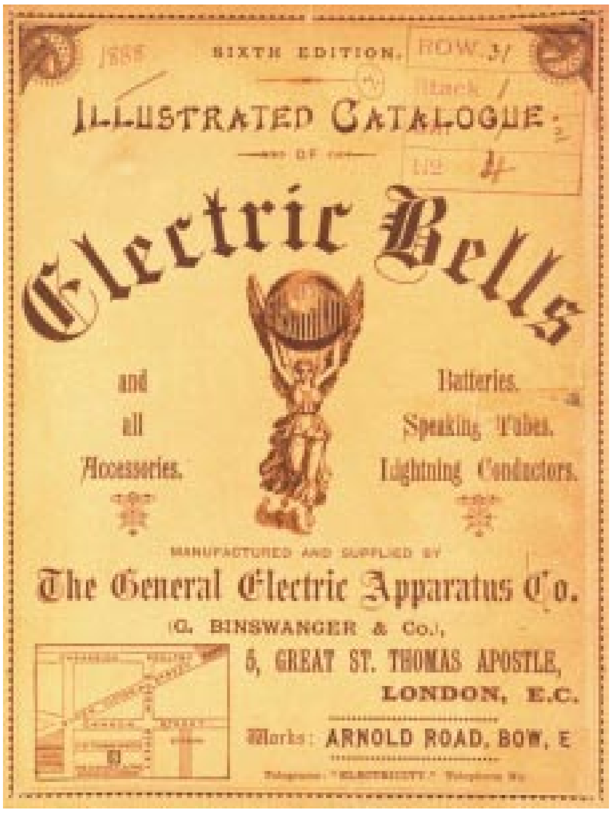
3 ***The founders of the General Electric Apparatus Company in 1892 (left to right): Hugo Hirst, Gustav Byng and Max Byng***

The Origin of the G.E.C.

As I could not make the agreement with Mr. Byng which satisfied me, and I did not like to act as his clerk, and began to feel my powers, I insisted that we ought to trade under a neutral name, and we took the name: 'General Electric Apparatus Company' (fig. 4), and I have still got the catalogue with 'General Electric Apparatus' but with 'Apparatus' struck out. When we took up these articles which were not apparatus, we thought it was inaccurate, and we dropped 'Apparatus' and that is where 'G.E.C.' comes from. It was still a private business, Mr. [G.] Byng was the proprietor, and it was only made a limited liability company in 1889.

Switches

The years 1886 to 1889 proved a success. We did so much business and we made so much profit, but I thought you would be more interested to know that the idea of the switch board in those days was something very original. The switches were made



4 ***An early (1888) catalogue produced by the General Electric Apparatus Company***

for us by two people; at the beginning only one. There was a firm in Bow: Coates Macdonald & Co.

The Manchester Company went smash and Coates and Macdonald were in that Manchester Company and they started for themselves down in Bow. We gave them all the orders, and Mr. Coates is still with us. In those days we made switches which were wooden blocks, and we thought we had made a wonderful discovery when we found when we put a spring on a lever instead of making any contact the current was still going through the moving parts. Of course, 50 ampères was something very big. Then we devised the idea of double contacts and then studied the question of springs.

Then I had an idea I took up. I actually took out a patent for putting switches on china; it seemed so simple; but we had never thought of it. A patent was granted, but the china people could not work the china; they could not screw china in those days and we had to devise means. If you wanted to fix anything you just had to drop a bolt through and fasten a screw on the back. What it meant was, that with the possibility of water running down the back, short circuits occurred, and the fires that were caused you can imagine. Then I thought of putting plaster of Paris in, but I visited in those days, and so did Mr. Byng, the china works, to make ourselves familiar with the way china was being made, and we devised certain things that we thought could hold on the cover, and eventually succeeded. That was a process which took over three or four years, but it proved very interesting because it made us experts.

We were the first who thought of china, and it gave us an outstanding position in the electric supply business (figs. 5 and 6); in four or five years afterwards the bulk of our business was derived from our speciality, of which we both had patents. It started with these difficulties on the part of makers in meeting the conditions. We had no personal experience but we met the engineers and met the users, took note of their complaints, and tried to improve.

The switchboard was something tremendous and we thought no one would ever be such a fool as to buy one. I will not go through the details, but our efforts at switches were not successful in the minds of some people, and Sir William Preece and some other Post Office people devised one for which we took a licence, and the idea was to put a new phrase in our catalogue to give us a lift up. That gave us the opportunity to know Post Office people, and we made a lot of money, not out of the switch, but out of the Post Office.

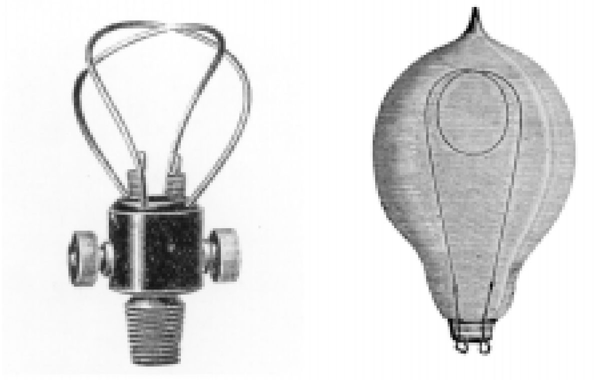
5 ***Main switches (from the 1889–90 'General List')***

6 *Domestic branch switches (from the 1889–90 'General List')*

Lamps

Then the next thing on that catalogue is lamps. Lamps were a monopoly. We could only buy lamps at Southampton and ship them for export, but we could not import lamps. The business was in the Edison and Swan Company and I called on the manager, hat in hand, saying I represented the G.E.C. and we should like to take up the electric lamps. His agents had 30%, and the list price for carbon lamps was 5/– each. I do not know the exact words he used, but it was to the effect they were quite well provided with agents and they did not want to have anything to do with a man like me, but they had a man named Dawson who was free to trade. We made an arrangement and our lamps were bought at fixed prices and we did quite a business with them.

Now, most of the lamps were made with little hooks; there was no socket on them, the lamp holder was a piece of wood with two 'U'-shaped springs, and the lamp rested on those springs which pushed it up (fig. 7). It was all very well on the first day, but here again, if you did not have German Silver wire, or even if you had, those springs got tired and the inevitable happened – the lamps burst or the holder burnt. Then the Vitrite people made brass sockets. We were for a time agents for the brass socket/holders with Vitrite, but there was no profit in it and nobody made money on it.

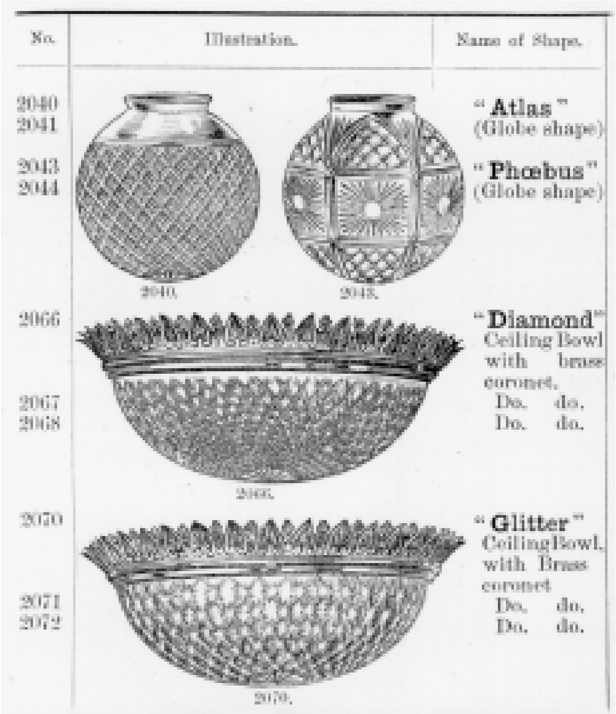


7 ***Wooden spring holder (left, from the 9th Edition of 'Electrical Supplies, 1898) and 'bottom loop' lamp (right, from the 1889–90 'General List')***

I then discovered that the Edison & Swan Company which, by that time, had come under different management (I am forging ahead a year or so) had a patent. I went to Mr. Page and said: "You have a patent and if you will uphold that patent I will be one of your licencees, but it means regulation of prices". We did a big business; our business from Edison & Swan Company amounted to something like £3,000 a year and the only trouble was we had always to have the auditors in the house and Mr. Byng fainted every time he saw the auditor.

Cables, Glassware and Carbons

Now, electric wires and cables we put in the list, with the idea that we ought to supply everything. Then I found there was a business to be done in glassware. Nobody had started glassware and every electric lamp wanted a shade. I visited the different glassworks and saw vases of all kinds of designs, and we broke them haphazard to see whether a shape would remain. All those shades that you see, the opal and the tulip or whatever they may be called, were the outcome of those visits to the glassworks. In order to sell them I conceived the idea of giving each shape a name and standardising the opening which I fixed at $1\frac{1}{8}$ [inches, or 28.6mm] for the lamp holder, $2\frac{3}{4}$ [70mm] for the small gallery, $3\frac{1}{4}$ [82.5mm] for the big gallery, and whatever was fixed is still ruling today, because others copied them, even the names. Then, once having a shape given a name, the customer could order it in any kind of glass, opal or frosted, or blue or yellow, or any colour he wished.

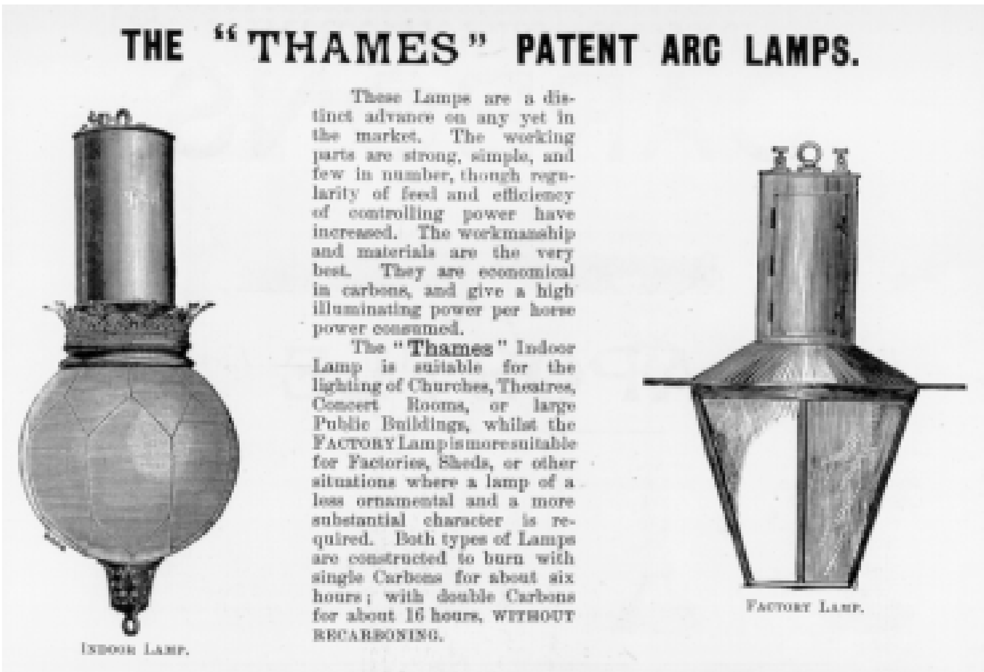


8 ***Cut glass shades (from the 1889–90 'General List')***

This led very quickly to a development of the glass business which played an important part in our concern, and we made ourselves very useful (fig. 8).

That in turn led to the supply of arc lamp/globes (fig. 9). At that time arc lighting was the general thing rather than the exception. Every arc lamp had a different shaped globe, and some of them were 18 inches [45cm] in diameter. The English glass blowers objected to blowing such big glass, and I was forced to make trips to the Continent to see whether I could buy them there. I did open up a source of supply, and for many years that led to a regular and profitable business in our stores in Thames Street, where later on Mr. Railing entered as his first job in the G.E.C. which was principally given up to glass ware.

The difficulty of selling carbons [for arc lamps] was firstly their expense. I remember getting every month one order from the South Kensington Museum from Major General Festings. 2000 pair invariably came on the last Saturday of the month and invariably meant £52 and something. How many thousand pairs would you supply at that price today? In going round I found that the average lamp trimmer did not know what they cost: he could not understand the invoices; he could not calculate the complicated prices of feet and millimetres and pence , and so on, and it was then that the idea occurred to me to give an all round price of 1/4d per millimetre per foot, or £1 per millimetre per 1000 feet, and that made it very simple to buy.



9 ***Arc lamps (from the 1889–90 'General List')***

(Part 2 of this account will appear in a subsequent issue of GEC Review and will include topics such as the European scene, the beginning of the electrical installation trade, the Crystal Palace Exhibition of 1891, the arrival of Max Railing, and the development of the business.)

In Brief

MARCONI COMMUNICATIONS

(website: www.marconicomms.com)

Marconi Communications Launches SmartPhotonix Family of Wavelength Division Multiplexing Products

Marconi Communications has introduced a world-leading family of optical equipment – the SmartPhotonix family of DWDM (Dense Wave Division Multiplexing) products that, for the first time, offer the benefits of optical transmission for both long-haul and metropolitan area networks. It was shown for the first time anywhere in the world at PT/Expo Comm China '98 exhibition in Beijing.

Parallel developments at Nottingham in the UK and Genoa in Italy have been integrated enabling Marconi Communications to offer DWDM solutions for both point-to-point and, uniquely, ring-based network topologies. The SmartPhotonix managed product range, available commercially in early 1999, comprises:

- the MSH 73 optical multiplexer, targeted at long-distance, point-to-point line systems;
- the MSH 75 optical amplifier for augmenting the signals over long distances; and
- The PMA 8, targeted at ring-topology Metropolitan Area Networks such as the City of London.

AWACS Upgrade Order from Boeing

Marconi Communications has won a £29 million order as part of a comprehensive modernization of the AWACS (Airborne Warning And Control System) aircraft operated by NATO (North Atlantic Treaty Organization). The order, from The Boeing Company, Seattle, is to develop a new on-board system for the AWACS aircraft to enable it to interrogate targets and identify friends and foes.

Marconi Communications, which has developed world leadership in electronic identification technology, is teamed with the US Company Telephonics to develop a system that maximizes commonality between the NATO and US fleets.

Installation of the new interrogator systems is expected to start in December as part of NATO's Mid-Term Modernization Programme for its AWACS fleet.

TETRA Systems for Croatia and St Petersburg

The organization responsible for generating and distributing electricity throughout Croatia – Hrvatska Elektroprivdea – has chosen a state-of-the-art TETRA (TErrestrial Trunked RAdio) system from Marconi Communications as a private mobile communications network for its engineers working in the field. The contract, worth £1.6 million, includes network design, installation, network management and training by Marconi Communications.

A TETRA digital mobile radio system is also to be supplied to the Russian city of St Petersburg for use in the underground railway – the Metro System. Marconi will supply four Switch Control Centres, 60 multiple-carrier base stations and a quantity of hand-portable and train-mounted mobile terminals. It is also providing specialized software enabling every one of the 230-plus trains to be contacted and a response generated within one second.

Major Contract for French Ministry of Defence

The French Ministry of Defence has awarded a contract worth £2.5 million to Marconi Communications for a maritime radio broadcasting system to enable information to be broadcast world-wide. The system – to be installed in France and its dependencies around the world over the next eighteen months – comprises over thirty Marconi High Frequency (HF) 10kW transmitters fitted with Marconi Digital drives that process the voice and data information, making it suitable for HF transmission. HF systems are particularly suitable for secure long-distance communications. An on-shore amplifier at 10kW can broadcast information over many thousands of kilometres to a receiver – and so to a telephone, computer or printer.

Marconi Upgrades Argentina's Communications Network

Marconi Communications, the European broadband network leader, has won new orders worth around £7 million (US$10 million) for equipment to upgrade Argentina's communications infrastructure. The Company's latest and most important contract to date is from Telecom Argentina, for optical bearer equipment to create a network of new rings serving business and residential customers in the cities of Cordoba, Rosario and Santa Fe.

Marconi Joint Venture Wins New Orders from Chinese Rail Ministry

Marconi Communications' joint venture company, Shanghai GPT, has won the first of a new series of orders from the Chinese Ministry of Railways (MOR), as part of a programme worth over 36 million (US$10 million) to upgrade the communications system on the country's rail network. The agreement is a milestone in the fast-developing role of Marconi in China, as Shanghai GPT will supply the Ministry with products sourced from both its UK factory in Coventry and the Shanghai factory.

Fibreway Opens the Telecoms Gateway to Europe

Construction has started on Europe's most advanced urban fibre network. Connecting the hub of telecommunications operators located on London's Isle of Dogs, Fibreway Limited is building a network capable of carrying over 2,000 optical fibres – providing enough capacity for the entire population of the UK to make a simultaneous telephone call. Fibreway's Isle of Dogs network will interconnect with the Company's 1,300km national network– much of it along British Waterways' canals – which links every city in the UK and offers major portals to the principal European and North America markets.

Marconi Signs Two Deals in Brazil

GPT Payphone Systems, a division of Marconi Communications, and DARUMA, Brazil's leading payphone supplier, have signed a collaborative agreement to enable them to attack the US$100 million Brazilian payphone market and other opportunities in South America. As part of a fixed network privatization programme, the Brazilian Government is set to double the number of payphones from 500,000 to over a million in a three-year timescale. This represents over 100,000 payphones per year.

Furthermore, Marconi Communications has reinforced its market lead in Brazil with a new £26 million order from the state telecoms company Telpar. This latest contract is for SDH (synchronous digital hierarchy) transmission equipment and a network management system, providing public and private telephony, plus links to the mobile phone system, for the state of Parana. Marconi will also supply long-distance communications for Parana, which is Brazil's second most industrialized region, covering an area of 200,000 sq km. The order strengthens Marconi's existing market leadership in the supply of telecoms network equipment to the country.

VIDEOJET

(website: www.videojet.com)

Cold Fill Returnable Bottle Ink

A trend in the beverage industry to move codes from the cap to the neck of the bottle has prompted the introduction of Videojet's latest *Ink*Source® ink, the 16-8540. This new black, ketone-based ink has been formulated specifically to provide a clean, crisp code onto the neck of the bottle, an area where excessive condensation and subsequent handling, prevents many inks from providing acceptable codes. *Ink*Source® 16-8540 exhibits superior adhesion to cold-filled returnable bottles at 2°C, with fast dry times of 1-2 seconds. The codes produced by this formulation offer excellent water resistance, including ice bucket immersion, but are also removable with standard 2-3% caustic wash. They do not fade on exposure to the sun and are resistant to typical food and beverage pasteurization and retort processes.

Videojet Triumph: Extraordinary Ink Jet Printing for Ordinary Applications

Videojet Systems International, Inc., has released the Videojet Triumph™ small character ink jet printer, a complete non-contact, ink jet imaging system that prints a variety of codes and messages in one-, two-, or three-line formats with additional features for custom applications. The Videojet Triumph is backed by ***Total***Source®,

Videojet's exclusive programme of complete customer support and services, including applications assistance, installation, operator training, technical support, maintenance, and field service. Only Videojet's ***Total***Source program provides customers with the industry's highest level of customer support, to ensure maximum coding productivity.

Adjustable Print Contrast and Bar Width Control for High Resolution Carton Printing

The new Videojet Apollo II Ink Jet Imager with NT Print Controller is a large-character, high resolution carton coding system that excels at printing bar codes, text and graphics onto corrugated containers or similar porous materials. Its high quality performance in this field of application results from the ability to adjust print contrast, as well as from features such as bar code width control, bar code magnification and vertical printing capability.

MATRA MARCONI SPACE

(website: www.matra-marconi-space.com)

The Birth of the First European Space Sector Company

The Lagadère and GEC Groups which, as of November 1990, had brought their space sector operations together under the structure of Matra Marconi Space, and which, in 1994, took over the space sector operations of British Aerospace, have signed an agreement with their new partners which will result in the birth of the first European space sector company. This company will integrate the space sector activities of Matra Marconi Space (51% Lagardère, 49% GEC), of Daimler Chrysler Aerospace AG and of Alenia Spazio. This new company will begin its life in 1999, after consultations between the partners and the granting of approval by National and European authorities.

AFRISTAR

– the first digital audio broadcasting satellite

The Afristar spacecraft, built by Matra Marconi Space for Alcatel as part of the Worldspace contract, was launched successfully from Kourou, French Guiana, on an Ariane 44L on 28th October 1998 at 22.16 (GMT). Worldspace has conceived and is developing the world's first global digital audio broadcasting satellite system. Matra Marconi Space is prime contractor for the Worldstar satellites while Alcatel Space being the prime contractor for the whole system which consists of four identical satellites: Afristar (21°E), Asiastar (105°E) and Ameristar (95°W) with the fourth, F4, as a ground spare.

The satellite system will provide multimedia broadcasting services, including audio, data and pictures, to an audience of more than 2.6 billion people all over the world. The high performance of the four spacecraft will allow reception by a new generation of low-cost radio receivers.

The payload was switched on during the 6th and 7th September and payload in-orbit testing began on 9th September. Singapore Telecom operators became involved in the operations activities from their Seletar ground station during the in-orbit testing. Control was then transferred to Matra Marconi Space operators at Chungwa Telecom's (CHT) Yangmingshan control centre on 27th September. CHT-I operations staff worked alongside the Matra Marconi Space controllers until control was transferred back to Seletar shortly before CPA (Certificate of Provisional Acceptance).

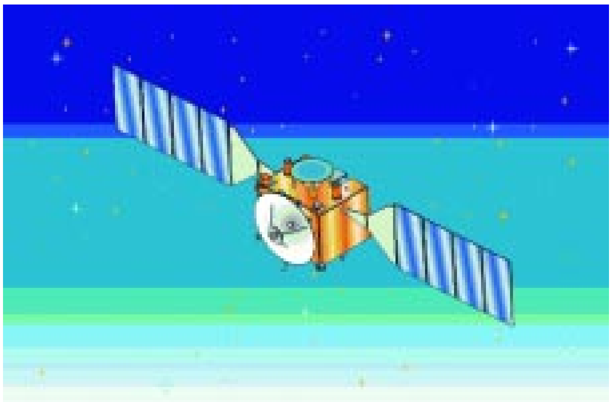
ST-1 Handed Over

Singapore Telecom and Chunghwa Telecom Co. Ltd. accepted the in-orbit test results and took title to the ST-1 satellite in Singapore and Taiwan at 1400 hours (0600 GMT) on 26th October 1998. In-orbit testing, completed on 24th September, met all requirements for in-orbit acceptance and confirmed the excellent performance of the spacecraft.

ST-1 was launched successfully on an Ariane 44P rocket from Kourou on 25th August 1998, at 23.07 GMT. The spacecraft separated from the launch vehicle and was injected into orbit twenty minutes later with pinpoint accuracy.

Matra Marconi Space Picked for Mars Express

Matra Marconi Space has been recommended as Prime Contractor for the Mars Express spacecraft by the Industrial Policy Committee of the European Space Agency. The contract for the design and development of this first European spacecraft to visit the planet Mars is worth £45 million (60 million ECU/US$ 70 million). Both French and UK sites of Matra Marconi Space will be involved. Development of the spacecraft should now proceed swiftly, to meet the deadline of an exceptionally favourable launch window early in



June 2003. The Mars Express spacecraft will be placed in an elliptical, quasi-polar orbit around Mars by Christmas 2003.

PICKER

(website: www.picker.com)

510k Clearance for Picker's FACTS Makes Venue Concept a Clinical Reality

FACTS ™, a fluoro-assisted computed tomography (CT) system developed by Picker International, Inc., has received 510k clearance from the US Food and Drug Administration (FDA). The FDA clearance of FACTS was the final step necessary to enable Picker to bring this new technology to medical sites world-wide. Venue ™ is a system of integrated CT, X-ray and stereotaxis products, consisting of FACTS, PinPoint ™ (an articulated frameless stereotactic arm), and a Picker CT scanner. Its multimodality capability allows radiologists to diagnose, intervene, and treat patients more quickly and more accurately, in the same room, in one episode of care.

WOODS AIR MOVEMENT

(website: www.woods-fans.com)

Fans for Cardiff Millennium Stadium

Woods Air Movement has won a major contract to provide a complete air extraction system for the new Millennium Stadium at Cardiff. For the past year, the home of Welsh rugby has been undergoing a rebuild programme to create a new all-seater stadium with a closing roof. The Stadium will play host to the next Rugby World Cup and will be used for concerts and sporting events all year round.

The contract was awarded by stadium mechanical and electrical contractors Drake & Scull Engineering Ltd., who needed to find one company capable of handling ventilation and acoustic requirements on such a large and varied scale.

Fresh Air from Woods in Italian Tunnels

The world's longest six-lane motorway tunnel, the 7.6km long Coté de Sorreley, is at Aosta in the Italian Alps; and, along with the neighbouring 3.2km long Signayes tunnel, it handles motorway traffic coming from Turin in the South, from the Mont Blanc tunnel to France, and the San Bernard tunnel from Switzerland. Both tunnels are being ventilated with the latest generation of Jetfoil fans from Woods Air Movement Limited. Woods won the order to supply a total of forty-four 1.60m diameter Jetfoil fans to the main consultant, the Società Iniziative Nazionali Autostradali (SINA). The order included the supply of fans, frames, anchors, sensor equipment and controllers.

Major Breakthrough in Fan Technology

The Compac-Climafan is a revolutionary fan design, developed by Woods Air Movement. The Compac-Climafan incorporates the latest in Woods' technology coupled to the new axial air-gap electric motor. Specifically designed for use in OEM heat transfer applications, where high performance, quietness and maintenance-free reliability are all factors, it is probably the most compact fan on the market for its rated output. Above all, the new fan is competitively priced, easy to install and can be produced to exactingly high standards in large numbers.

MARCONI ELECTRONIC SYSTEMS

(website: www.gec-marconi.com)

US Lightweight Howitzer Programme Engineering Manufacture and Development (EMD)

The Land and Naval Systems (LANS) Group of Marconi Marine, formerly VSEL, Barrow -in-Furness received a major boost with the announcement that it has assumed the role of prime contractor from its team member, Textron Marine and Land Systems (TM&LS), to complete the development of the world's lightest long-range 155mm howitzer. The purpose of the programme is to replace the existing M198 howitzers in the US Marine Corps and US Army with the new system, designated XM777, a 9000 pound howitzer designed and developed by Marconi Marine LANS.

The XM777 is a unique lightweight howitzer capable of firing 155mm artillery projectiles to 30km whilst also being able to be transported rapidly under medium lift helicopters to the theatre of operation. The system's unconventional design plus the extensive use of lightweight materials, including titanium and aluminium alloys, makes it a world leader in the towed artillery market.

Marconi Seaspray Order for Edinburgh

Marconi Avionics has been awarded a contract by the German Federal Office for Defence Technology and Procurement (BWB) for Seaspray radars that will equip Federal German Navy Lynx helicopters. The contract is valued at more than £15 million and is the largest order for Seaspray radars to be awarded to the Company. The contract will ensure continued production of Seaspray radars in Edinburgh until 2002. The order builds on 30 years of association between the Seaspray radar and the GKN Westland Lynx helicopter, during which time Marconi has supplied over 400 radars.

Marconi/Honeywell Production Standard Helmet Mounted Sighting System (HMSS) Flies on Jaguar '97

The production standard Marconi/Honeywell Helmet Mounted Sighting System (HMSS) has been flown, for the first time, on a Royal Air Force (RAF) Jaguar GR3A aircraft (No. XZ399) at the Defence Evaluation Research Agency (DERA) site at Boscombe Down. The HMSS is being added to the aircraft as part of the Jaguar '97 upgrade package to provide a lightweight, reliable, low-cost solution to cueing, sensor slaving and off-boresight missile aiming requirements. The system will be used in conjunction with the Marconi Thermal Imaging and Laser Designator (TIALD) pod and the Matra-BAe Advanced Short Range Air-to-Air Missile (ASRAAM).

RAF Tornado AMLCD Displays Contract

Marconi Avionics has announced the award of a contract by the Royal Air Force, valued at more than £30 million, for the supply of latest generation Active Liquid Crystal Displays (AMLCD) colour displays for their Tornado aircraft. The RAF programme is designated Television Tabular

Displayed Displays (TV-TADs). The initial contract award covers 24 units to be delivered over the next 15 months. Options exist for further blocks of 200, 300 or 400 displays for the remaining RAF Tornado fleet. The new display is based on Active Matrix Liquid Crystal Display (AMLCD) technology developed by Marconi Avionics in Edinburgh. The new display has high brightness for use in full sunlight, and is fully compatible with Night Vision Goggles for night operations.

Marconi Launch Production for Eurofighter Typhoon ECR90 Radar

Marconi Electronic Systems has announced the award of a contract by British Aerospace for production of the ECR90 radar that will equip the Eurofighter Typhoon. ECR90 is a next generation high performance pulse Doppler, multimode radar, and is the primary sensor for the aircraft. The contract covers an initial batch of 147 radars and spares that will meet the production requirements for the first tranche of Eurofighter Typhoon aircraft to be built by the Eurofighter consortium for the four partner nations – Germany, Spain, Italy and the UK.

Alenia Marconi systems

(website: www.aleniamarconisystems.com)

First Flight of Brimstone

On 17th December 1998, a MoD (PE) Tornado ground attack trials aircraft successfully flew the first handling and clearance flight trial with 12 Alenia Marconi Systems' Brimstone missiles. Alenia Marconi Systems and British Aerospace Military Aircraft & Aerostructures (BAe MA & A) jointly conducted the trial of the advanced anti-armour weapon from BAe's Warton facility in Lancashire, UK. The first flight on Tornado represents the successful achievement of the latest milestone in the programme which commenced in November 1996.

Elusion Delivered to RAF

Alenia Marconi Systems has delivered four Elusion Electronic Warfare Training Systems to the Royal Air Force (RAF). Elusion is being used by the Air Warfare Centre, Operational Doctrine and Training Department (OD&T) at the RAF College Cranwell to provide a new dimension to their Electronic Warfare and other specialist training courses. Elusion enables the user to create an Electronic Order of Battle (EOB) that is superimposed onto a 3-D terrain map derived from Digital Terrain Elevation Data (DTED). In this virtual 3-D world the RAF can plan and 'fly' in a realistic environment over an accurate representation of the real-world terrain in their operational area.

SAWCS Contract Awarded

Alenia Marconi Systems has been awarded a contract for £40 million plus for the UK's Submarine Acoustic Warfare Command System (SAWCS). SAWCS provides the Royal Navy with an effective defence against the latest generation of torpedoes.

HMS *Invincible* Combat System Upgrade

Alenia Marconi Systems has been offered a major contract to upgrade HMS *Invincible*'s combat system. The upgrade will bring the ship's combat system up to the same standard as those fitted to HMS *Illustrious* and HMS *Ark Royal* and includes the introduction of an all-colour Operations Room.

REDRING®

(website: www.redring.co.uk)

AD1 Auto-dry Hand Dryer

The stylish AD1 Auto Dry hand dryer is the latest addition to Redring's Washroom Solutions range, combining ultra-modern looks and the ultimate in hygienic operation together with value for money. Designed for light to medium usage installation where hygiene is a prime consideration, the AD1 is ideal for surgeries, clinics and food preparation areas. Both lightweight and compact, the new 1.5kW hand dryer will also add a contemporary touch to the small office environment.

Advantage Pumped Electric Shower

Innovative and stylish in design, the new Advantage Pumped Electric Shower from Redring is the ideal solution for installations where there is insufficient water pressure for a traditional instant electric shower. Plumbed directly into the cold water cistern, the Advantage will heat water instantly. As the Advantage incorporates a 230/240V motor and pump assembly to boost water flow, it can deliver up to 7 litres of water per minute. Simple to use, the Advantage features a single numbered rotary control for start/stop and flow/temperature selection and a separate rotary knob for high or low-power selection.

Avery Berkel

(website: www.averyberkel.com)

Totalgaz and Avery Berkel Develop New Stand-alone Solution for Gas Filling

Totalgaz, a division of Total Oil Great Britain Ltd, has placed orders work £100,000 with Avery Berkel to introduce the most accurate and efficient LPG filling machines to its liquid petroleum filling plants. As one of only four gas filling companies with ISO 9000 approval, Totalgaz trades on quality and reliability.

In the past, LPG industries requiring the benefits of digital weighing have had to endure cumbersome installations, with equipment located in bulky 'flame-proof' enclosures. For safety, LPG filling operations are normally located in areas remote from main buildings. Cabling to these areas is not always viable.

Employing the proven Avery Berkel Loadstar Ex intrinsically-safe indicator, winner of the prestigious MIAA award for development within industry, Totalgaz has now brought the benefits of precision weighing into its filling process.

Working in partnership, Totalgaz and Avery Berkel have moved the LPG filling industry into the 21st century, with the development of a safe, ergonomically designed electronic gas cylinder filling system. This potentially creates the most accurate gas filling system in the UK today.

Calor Gas Continues to Invest with Avery Berkel

Calor Gas has placed a further order with Avery Berkel for 31 stand-alone R217Ex filling machines – Avery Berkel's latest development for the LPG industry. The package includes data capture to a safe area PC at three of their filling sites in the UK. This order follows the successful installation of ten carousel-mounted LPG filling scales at their Grangemouth plant, believed to be the first all-electronic filling carousel in the UK LPG industry.

Calor Gas has been working in conjunction with Avery Berkel for over eighteen months, developing the software within the Avery Berkel intelligent industrial indicator in order to meet the exacting requirements for filling procedures within its plants. The new system ensures maximum filling accuracy, ease of operator use and meets safety requirements.

Technology News

The Speechdat Project for Spoken Language Databases

SpeechDat

The Commission of the European Community (CEC) is funding a collaborative programme of work to produce databases in various languages to meet defined specifications. Marconi Communications (formerly GPT) is one of the main partners†. Also involved in the project, as a subcontractor, is Marconi Research Centre (MRC).

The languages covered within Speechdat II are the main European languages, which include British English*.

Aims of the Project

The project was initiated to fulfil the demand for speech resources (that is, databases) to assist in the development of speech recognition technologies and speaker verification. Many European companies are active in the field of voice-driven teleservices and delivering the necessary speech technology. The aim is to produce speech databases recorded over the telephone network that meet the same requirements specification.

Such databases are needed to allow the development of multilingual voice servers by European industries, with potential for export.

The British English databases include a Fixed Network Database (FDB) of 4000 speakers and a Speaker Validation Database (SDB) of 120 speakers × 20 calls each, recorded by GMRC, and a Mobile Network Database (MDB) of 2000 speakers recorded by BT. FDBs are being created for all languages stated above. The SDBs and MDBs are being created for selected languages only. The aim of the MDB is to improve channel adaptation and noise reduction techniques, whilst the SDB is used in speaker verification algorithms.

Currently, many automated teleservices rely on isolated word recognition – that is, words can be spoken in isolation only after a system prompt. Speech recognition systems are being developed that can perform **continuous** speech recognition (that is, no pause is required between words). When keywords are uttered within a phrase the recognizer will be able to extract the relevant command and discard the rest. The overall aim is to make speech recognizers more user-friendly, so that, for example, users will be able to interrupt recorded prompts at any time and use natural, spontaneous speech when interacting with automated systems.

Speech Collection

The two complementary databases were recorded by MRC using the same recording platform. Speakers for both were recruited by a Market Research company in accordance with specified requirements. The databases were validated and are accompanied by design documentation, stating any deviations from the specifications.

In order to elicit utterances that conform to the requirements specification, speakers were provided with prompt-sheets and the recording platform gave a verbal prompt for each item – that is:

'please say item 2 after the tone'.

Forty-six items were recorded for each speaker for the FDB (of which 40 were mandatory) and 22 (of which 21 were mandatory) for the SDB. The FDB contains spontaneous utterances that were prompted by a verbal question such as:

'do you think it will rain tomorrow?'

† Other partners include Siemens, British Telecom, Centro Studi E Laboratori Telecomunicazioni, Institut Dalle Molle d'Intelligence Artificielle Perceptive, Knowledge, Lernout & Hauspie, Matra, Philips, Portugal Telecom, Speech Processing Expertise Centre (SPEX), Vocalis (the contractors). Also involved in the project, as associates or subcontractors are Aalborg University, University of Munich, University of Maribor, Swiss Telecom PTT, University of Patras, Tampere University of Technology, Kungl Tekniska Hogskolan, INESC, Universitat Politecnica de Catalunya and Telenor.

* Other languages are Belgian French, Danish, Dutch, Finnish, Finnish Swedish, Flemish, French, German, Greek, Italian, Luxembourgish French, Luxembourgish German, Norwegian, Portuguese, Slovenian, Spanish, Swedish, Swiss French, Swiss German, and Welsh.

The mandatory items included:

- phonetically-rich sentences,
- phonetically-rich words,
- keywords (that is, those used in association with teleservices),
- numbers,
- dates,
- times,
- names,
- money amounts, and
- spelled words.

All calls had to have at least 95% of the defined items recorded correctly.

For each speaker, information such as age, sex, and accent region was provided and, for the SDB, additional details such as health, tiredness and stress levels were noted. The label files that accompany the speech files contain these data. Tables of call data are also provided to allow easy access to the type of call required – for example: female, aged around 37, from the London area.

To enable users to access the recorded information, each item was annotated to provide a written interpretation of what was actually said. At the same time, non-speech (for example, background noise) symbols were added. This information is also stored in the label file. A lexicon is produced based on the contents of this field. All uttered words are included in the lexicon and a phonemic transcription is given. Where there are different pronunciations for the same word – for example, read (r e d / r I: d) – the alternative versions are given. However, the variations caused by accent region have not been reproduced as phonemic alternatives. These phonemic entries can be used to identify test data for speech recognition testing of a particular phoneme, as required.

Other Related Projects

The Speechdat project work continues with Speechdat (CAR) which is collecting data in nine languages recorded from GSM◆ phones in motor vehicles. This project is also assessing voice control for in-car equipment (for example, radio). In addition, Speechdat (E) is collecting data from Eastern European nations, whilst SALA is a South American project collecting data to conform to Speechdat specifications.

Finally, another European collaborative project, COST 249, is reviewing continuous speech recognition over the telephone. This project is intended to obtain the best performance from speech recognizers, and the collaboration enables exchange of useful information as the testing is performed.

◆ Global Systems for Mobile Communications

Availability of the Databases

The Speechdat II databases are available through ELRA (European Language Resources Association), and sales of resources for the first quarter of 1998 were up six-fold against the equivalent period for 1997. All databases are distributed in identical format on CD. The British English FDB is contained on 20 CDs and the SDB on 8 CDs§.

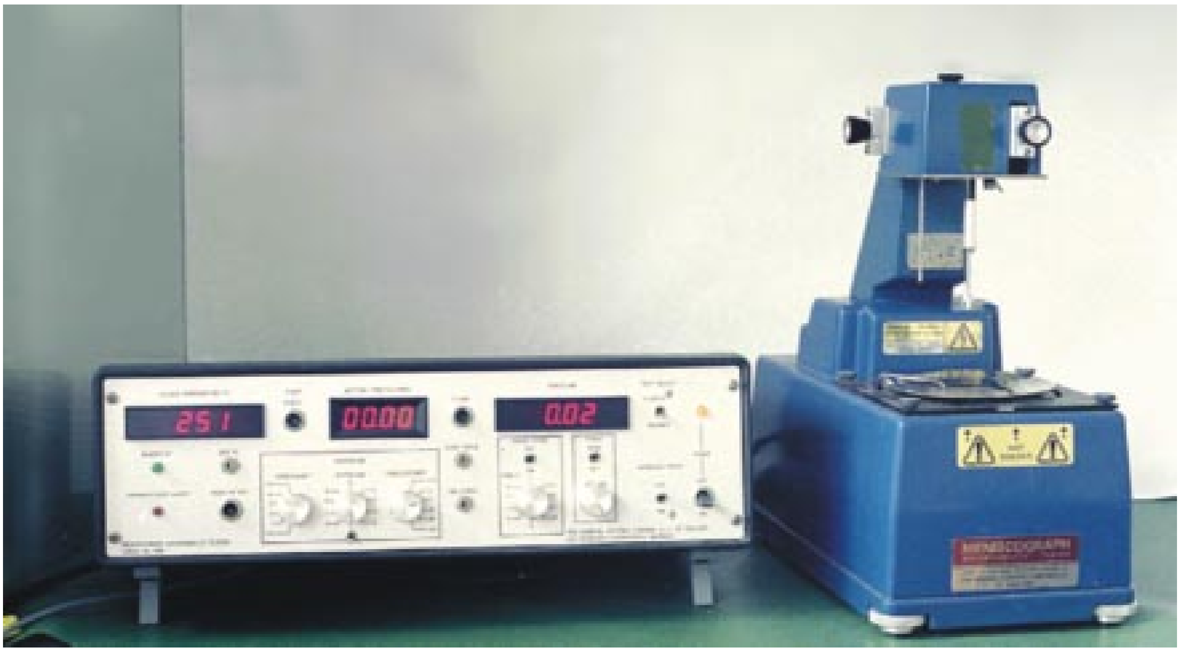
§ For further information on the database and speech recognition please contact Sharon Wheatley (sharon.wheatley@gecm.com) or Steve Ascham (steve.ascham@gecm.com), Marconi Research Centre, Marconi Technology Centres, Elstree Way, Borehamwood, Hertfordshire, WD6 1RX. For further information on the availability of the British English FDB and SDB databases, please contact Graham Fenner (Graham.Fenner@marconicomms.com), Marconi Communications Limited, Discovery Court, 551-553 Wallisdown Road, Poole, Dorset, BH12 5AG.

The GEC Meniscograph

The GEC Meniscograph is able to assess qualitatively and quantitatively the wetting of liquids on various substrates and provides a flexible development or quality process control tool, measuring the critical parameters of the wetting process. The equipment uses the wetting balance technique and records changes in the surface tension with time.

The GEC Meniscograph features are:

- A wide range of immersion speeds, depths, and times. Temperature control from ambient to 450°C.
- Sample contact detection by high-frequency electrical signal, or by sensing the upthrust caused by contact with the liquid.
- Windows software for data handling, and exporting to all popular spreadsheets. Facility to set the pass/fail criterion in the data handling software.
- Provides a complete picture of the way in which any liquid or substrate wets under selected conditions.



1 ***The GEC Meniscograph***

- Suitable for use in product development, production, and goods inspection.
- The Meniscogaph can be used to test the wettability of solders, adhesives (liquids, dispersions and hot melts), and surfactant systems.

For further information please contact:
Pete Hawkins, Chief Chemist,
Marconi Materials Technology Ltd.,
Marconi Technology Centres,
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Fax: +44 1327 356775
Internet: www.gmmt.co.uk

VERA: an Experiment to Derive a Cost-effective Verification Process

The rising cost of testing is driving industry to revise its processes and techniques in order to meet the complexity of future systems in an economical way. Software testing is key to gaining confidence about the correctness of the code, but testing techniques tend to be labour-intensive and hence expensive. The aim of the VERA (Verification, Evaluation, Review and Analysis) experiment was to investigate the balance between the use of review and testing techniques to provide cost-effective error detection for real-time software systems.

VERA was a process improvement experiment (PIE) funded by ESSI (European Software System Initiative). The experiment started in 1997 and has lasted for eighteen months. It has been conducted by the Radar Systems Division (RSD) of what is now Alenia Marconi Systems (at Chelmsford) and the Marconi Research Centre, Great Baddow. Other verification and validation (V&V) practitioners within Marconi Electronic Systems have contributed to VERA via the three interactive workshops that have been held during the experiment. The final results from the VERA experiment were presented at EuroSTAR'98 in Munich, Germany, December 1998 and at the Marconi Software Engineering Technology Group (MSET) seminar, 'Improving the V&V Process', on the 8th of December 1998.

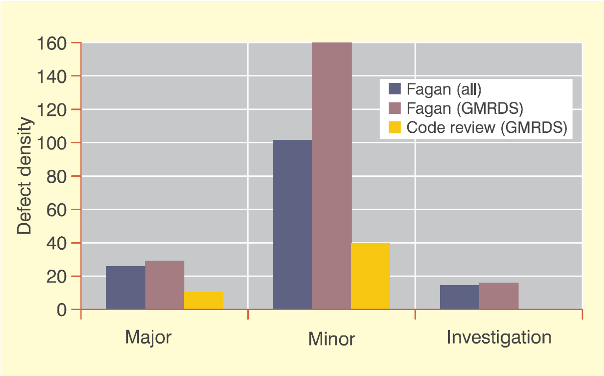
The project involved the analysis of existing metrics for code reviews and Fagan inspections, experiments with automated review techniques supported by Rational's† Ada Analyzer and experiments with automated testing techniques supported by Rational's TestMate™. The tool experiments were performed on a self-contained module of a real project within RSD and the results compared to the actual code review performed on that software. The techniques were assessed in terms of efficiency – to determine the effort involved in detecting defects, and effectiveness – to determine how many defects the technique detected.

† Rational Software Corporation, 18880 Homestead Road, Cupertino, CA 95014, USA. Phone: 00-1-408-863-9900. Fax: 00-1-408-863-4120. Email: info@rational.com. Web: www.rational.com/

Comparison between Code Review and Fagan Inspection

RSD took the decision in 1996 to adopt Fagan inspection as an alternative to the review process. The VERA experiment was able to analyse the metrics collected during Fagan inspections in order to evaluate the impact of inspections on the V&V process.

It was found that, on average, Fagan inspections find two-and-a-half times more major defects than code reviews (fig. 2). It is believed that this improvement can be attributed to the distinct roles for each inspector, the constraints to limit the rate of review, and the size of the document to be examined.



2 ***The average defect density per technique***

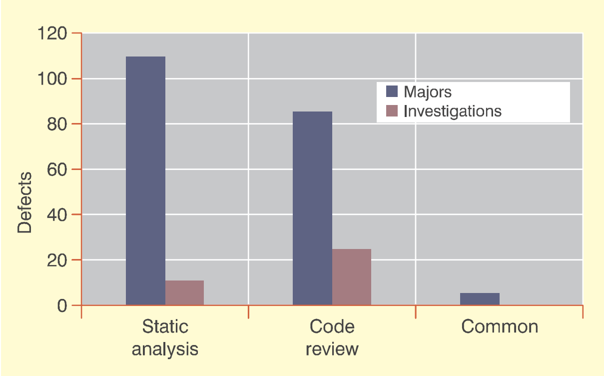
Finding defects early in the life cycle is paramount. Although the effort required to perform Fagan inspections is greater than the effort required to perform code reviews, the significant reduction in the predicted effort required for the integration test phase means that Fagan inspection is far more cost-effective overall.

The impact of individual engineers on any process is also extremely important. The VERA experiment results suggest that the more experienced engineers are in the language and application domain, the more defects are found during a Fagan inspection. This result contradicts the generally-accepted view that any competent engineer can review effectively.

Comparison between Static Analysis and Code Review

Static analysis is the activity of verifying software without executing it. Tool support for static analysis can (amongst other things) perform checks to detect coding violations and control-flow anomalies automatically (fig. 3).

With no prior knowledge in the application, the VERA experimenters completed the static analysis 34% faster than the reviewers reviewed the same code and detected 26% more major defects.



3 ***The total number of defects found per technique***

However, a significant number of defects were found, not by means of the tool, but by the experimenter whilst analysing the code. Code review and static analysis appear to be complementary, because only 5% of the defects found were common to both techniques. This is a major finding of the VERA experiment and is believed to be because the two techniques target different types of defects.

Automatic Test Case Generation

TestMate™ is still under development and various problems were encountered with the tool. In particular, the tool did not support certain data types (such as arrays and records of complex data types). Consequently it was only possible to use TestMate™ on approximately 7% of the units within the baseline project software. Although four major defects were detected, these required 120 hours of effort.

It is anticipated that many of the limitations encountered during the VERA experiment will be fixed in later releases of the tool.

Conclusions

The lack of a theoretical framework to determine objectively how much testing is required is problematic for the testing of complex software systems. The results of the VERA experiment provide guidance on which techniques are more cost-effective. From a technical point-of-view, the main lessons learned, are that:

- *Fagan inspections are more effective than code reviews*. Fagan inspections were shown to detect two-and-a-half times more major defects than code reviews.
- *static analysis is effective at finding major defects and finds different types of defects to code reviews*. Static analysis found 26% more major defects than code review of the same code. Only 5% of the defects were found by both processes.

- *automatic test case generation is currently difficult for the type of code used in the baseline project*. The versions of the TestMate™ tool used within the VERA experiment do not support certain Ada constructs. This meant that it was possible to test only about 7% of the units of the baseline project.

From a business point-of-view, the results of the VERA experiment show that:

- *the most cost-effective V&V process for software is static analysis coupled with Fagan inspections*. Performing static analysis and Fagan inspection on a typical piece of code is likely to result in the detection of three times as many defects as performing a code review. Although the effort required to perform static analysis and Fagan inspection is greater than the effort required to perform code reviews, the reduction in the predicted effort required for integration testing means that it is far more cost-effective overall.
- *the skills of the people performing a code review are vitally important to the effectiveness of the review*. The skills of the team members are less important during a Fagan inspection but do still have an impact.
- *static analysis, using 'Ada Analyzer', can be performed by competent engineers who have little or no domain knowledge*. This is an important finding because there is often a shortage of people with domain knowledge.
- *a formal process only produces consistent results if the rules of the process are followed*. Similarly, automating a process produces repeatable results only if use of the tool is controlled (for example by a code of practice).

Acknowledgments

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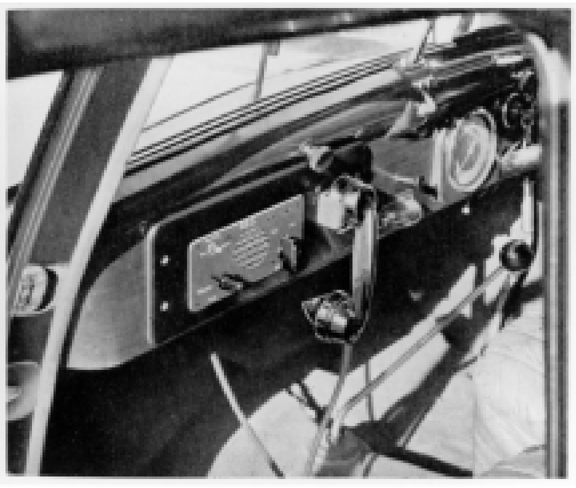
50 Years Ago

Typical mobile installation showing the transmitter/receiver in the luggage compartment of a car

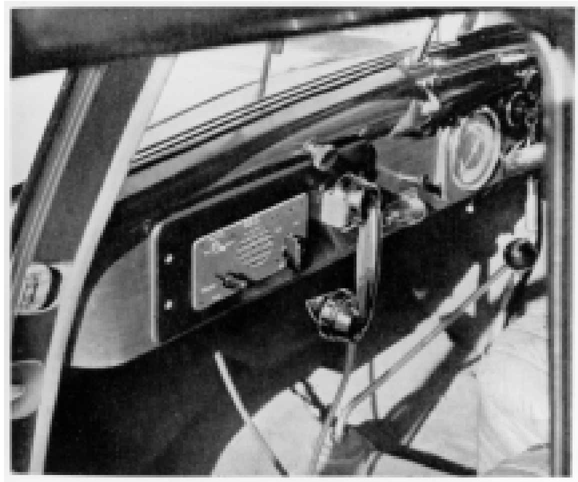


Mobile controller installed on the dashboard of a car

(From 'Applications of V.H.F. radio' by E.W. Northrop, GEC Journal, XVI, 4, pp. 184-196, 1949)

50 Years Ago

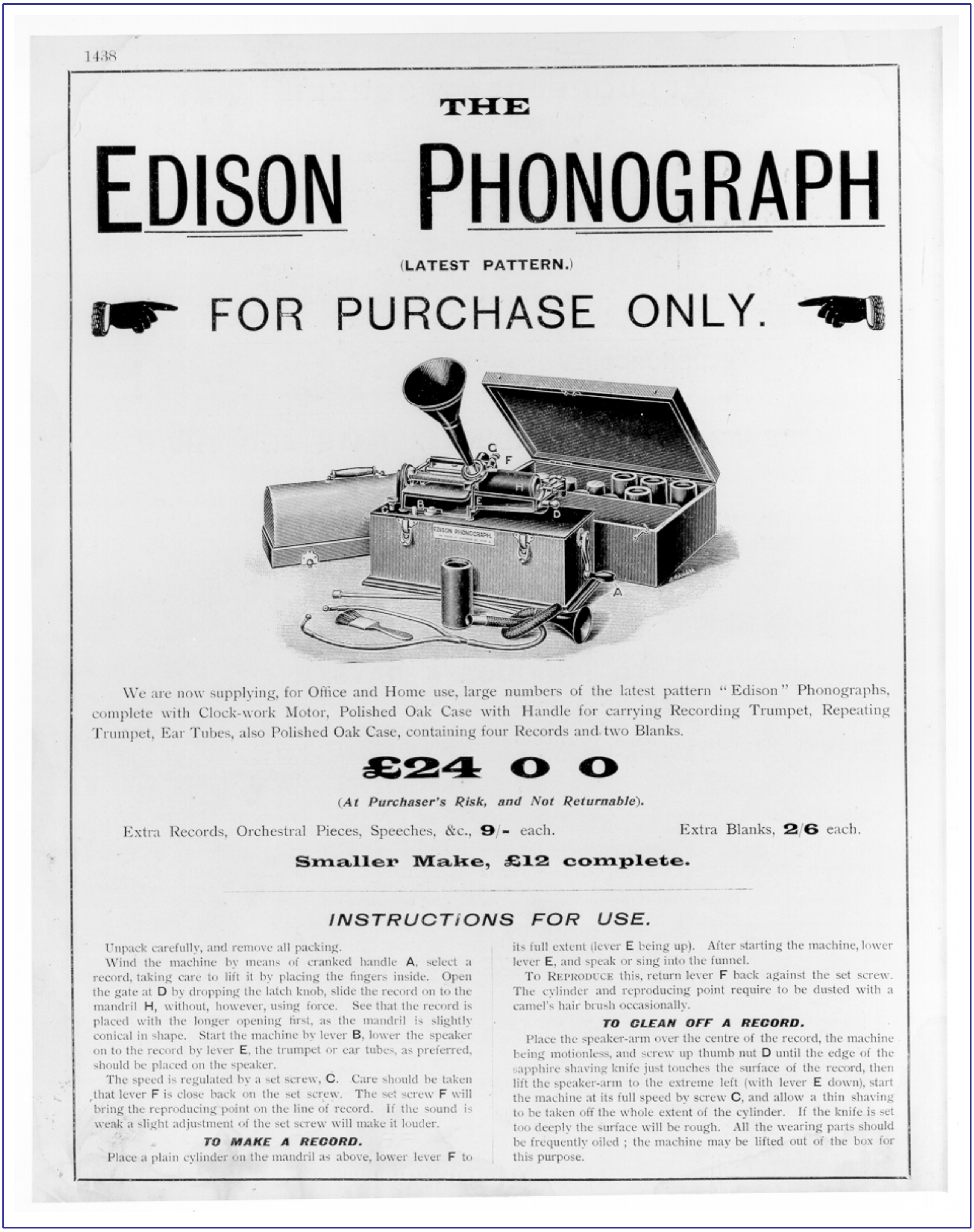
Typical mobile installation showing the transmitter/receiver in the luggage compartment of a car



Mobile controller installed on the dashboard of a car

(From 'Applications of V.H.F. radio' by E.W. Northrop, GEC Journal, XVI, 4, pp. 184-196, 1949)

100 Years Ago



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INSTRUCTIONS FOR USE.

Unpack carefully, and remove all packing.

Wind the machine by means of cranked handle **A**, select a record, taking care to lift it by placing the fingers inside. Open the gate at **D** by dropping the latch knob, slide the record on to the mandril **H**, without, however, using force. See that the record is placed with the longer opening first, as the mandril is slightly conical in shape. Start the machine by lever **B**, lower the speaker on to the record by lever **E**, the trumpet or ear tubes, as preferred, should be placed on the speaker.

The speed is regulated by a set screw, **C**. Care should be taken that lever **F** is close back on the set screw. The set screw **F** will bring the reproducing point on the line of record. If the sound is weak a slight adjustment of the set screw will make it louder.

TO MAKE A RECORD.

Place a plain cylinder on the mandril as above, lower lever **F** to its full extent (lever **E** being up). After starting the machine, lower lever **E**, and speak or sing into the funnel.

To REPRODUCE this, return lever **F** back against the set screw. The cylinder and reproducing point require to be dusted with a camel's hair brush occasionally.

TO CLEAN OFF A RECORD.

Place the speaker-arm over the centre of the record, the machine being motionless, and screw up thumb nut **D** until the edge of the sapphire shaving knife just touches the surface of the record, then lift the speaker-arm to the extreme left (with lever **E** down), start the machine at its full speed by screw **C**, and allow a thin shaving to be taken off the whole extent of the cylinder. If the knife is set too deeply the surface will be rough. All the wearing parts should be frequently oiled ; the machine may be lifted out of the box for this purpose.

(From 'Electricity', the Complete Catalogue of the General Electric Company, p. 95, 1898-9)

Techbriefs

A selection of technical information available from GEC's Technology Centres

Marconi Technology Centres
Marconi Materials Technology Ltd.
(Caswell)

GaAs MMICs – products include: amplifiers, attenuators, switches, ASICs, fibre-optic MESFETS, and wireless ASICS.

Optoelectronics – standard products include: DFB multi-quantum well lasers, GaAs Mach-Zehnder optical modulators, high-speed InP photodiodes, broad-band LEDs, and fibre gratings; special products include: tunable DBR lasers, microwave optical transmitters, microwave optical receivers, and micropackaging.

Materials – products include: radar absorbent materials, radar signature management, radomes and RF windows, elastomeric absorbers, and broad-band absorbers.

CVD Diamond – for coatings, optical windows, thermal management substrates, and as a free-standing material for a variety of other applications.

Marconi Technology Centres
Marconi Research Centre
(Great Baddow)

M215/2 ***Propagation and system studies*** – research and consultancy service in all aspects of radio system operation, from fundamental propagation assessments to system planning and simulation of complete networks.

MA302 ***Microwave antenna test facility*** – first-rate near-field test facility for rapid and accurate characterization of antennas in the 1-18GHz band.

MA303 ***Trainborne communications antennas*** – design and supply of custom antennas to the train communications industry.

MC110 ***COVMOD/Express*** – mobile radio coverage prediction software, release 2.1 for Windows NT, Windows 95, Sun and HP.

ME614 ***Field programmable gate arrays*** – a versatile way of providing connectivity and interface functions for existing equipments and arrays of specialist devices.

ME615 ***JAWS - SHARC-based DSP design*** – high-performance, cost-effective DSP VME module using a high specification Field Programmable Gate Array.

MO407 ***Laser Doppler anemometry for clear air wind speed measurements*** – a system using the optical backscatter from a focused laser beam to determine axial air speed.

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