Air defence radar for the 1980s

by J.W. Sutherland, M.A., C.Eng., F.I.E.E.

The modern air-defence radar has become a very sophisticated piece of equipment. It has to be if it is to operate successfully in a hostile natural and electronic environment in time of war. But what are the characteristics that need to be incorporated to make the modern Martello Tower effective?

The objective of air-defence surveillance radar is to provide full data on all targets in the specified airspace, under all conditions, both natural and man made. The utilisation of these data will range from early warning, the provision of 'tracks' (that is, a continuity of positional information, speed, direction of flight, identity, strength etc., based on the correlation of successive 'plots' on each target; data that are necessary for the conduct of an air battle) to the detailed continuous target data necessary for weapon engagements.

The air-defence radar must deliver its information in the presence of a number of constraints. The physical constraints are, first, the 'radar horizon', below which targets will not be seen; conventional radar, and other forms of microwave transmission, are virtually line of sight, but there is a small amount of refraction, and range calculations can be made on an approximate 4/3 earth rule, i.e. assuming that the earth has a radius of 4/3 its true radius. Secondly, one is concerned with natural 'clutter', the unwanted radar returns from various features of the terrain, from rough seas, cloud and precipitation. Fortunately, techniques of minimising natural clutter are well advanced, and indeed improving year by year, and some of these ideas will be discussed later in this article.

John Sutherland is the managing director of Marconi Radar Systems Ltd., Writtle Road, Chelmsford, Essex, England

0013-5127/79/100694 + 05 $01.50/0
©IEE:1979

1 Recently completed air-defence radar station in Shetland

Finally, one has intentional man-made interference, designed by an offensive force to deny information to the defender, and to which is ascribed the generic title of electronic warfare. The technology of electronic counter measures (e.c.m.) and of electronic counter-counter measures (e.c.c.m.) has been growing fast in the last two or three decades, and the e.c.c.m. performance — the antijamming performance — of a modern air-defence radar is undoubtedly its most significant characteristic and its most significant selling point, since the vital importance of electronic warfare has been appreciated in recent years by air forces around the world.

Jamming capability in strike aircraft is now so sophisticated and its deployment so carefully planned by offensive forces that, without the best possible e.c.c.m. facilities, it is true to say that a country is virtually defenceless against air attack.

The prime requirement of any service equipment is cost effectiveness in its broadest sense. In a civil application, for example, an en-route radar for air-traffic control, an authority will probably buy at the cheapest possible price down to a very basic minimum acceptable standard, and no more. The operation of the radar takes no account of electronic warfare, of vulnerability to attack and, incidentally, requires positional data in plan co-ordinates only. On the other hand, a military radar, although engaged on surveillance of the same airspace, operates to entirely different standards: much smaller targets, more detailed positional data, ability to cope with attack by hardening or by mobility, and, above all, by maintaining its performance in a severe jamming environment. It is in this case that the old adage 'you get what you pay for' comes into its own. If a country sees its air-defence radar as true wartime equipment, designed for operation in an environment of full hostilities, rather than as a means of policing the peace, there can be virtually no compromise on excellence and performance. The compromises are only between physically incompatible parameters.

The potential purchaser of this kind of equipment is faced with a difficult problem: if he insists on fixed-price competition and writes a procurement specification, he is inviting his supplier to cut corners, since he cannot give credit for performance in excess of the specification, and he will certainly force some contractors to degrade performance so that the specification is just achieved.

The air-defence environment is a demanding one on all equipment, whether it be land based, airborne or shipborne. Land-based equipment may be static, with permanent buildings, a degree of blast protection, perhaps with the antennas protected by radomes; or it may be transportable by road and air with the capability of rapid redeployment. Air-defence equipment for airborne surveillance faces special constructional problems since light weight is of cardinal importance, in addition to the difficulty of extracting signals from a rapidly moving platform. Air defence at sea poses further special environmental requirements: of robustness, resistance to salt and funnel-gas corrosion and of operation from a moving base.

Having examined the broad background to air defence, it is now appropriate to discuss some of the techniques that are important for radar in the 1980s and where technology has advanced in recent years.

The choice of frequency band and the use of frequency within the band are vitally important. Surveillance radars will generally be operated in the 10 cm or 23 cm wavelength bands (formerly coded S-band and L-band, but now known sometimes as E&F-band and D-band). Each band has particular virtues: obviously, for the same size of antenna, the shorter wavelength will give a narrower beam width; this means, on the one hand, greater angular discrimination, but, on the other hand, fewer radar pulses to strike the target and thus less effective signal processing against clutter.

On a purely physical calculation, the reflection from a conducting sphere is inversely proportional to the 4th power of the wavelength, and therefore, as one would expect, the radar reflections from rain etc. are considerably less at the longer wavelength. On aggregate, the merits of 23 cm radar somewhat outweigh those of 10 cm, but a mixture of the two can provide the best of both worlds. This may be actually in a single radar, or by deployment of radars at both wavelengths in the same system.

Fig.1 shows the new radar installation in Shetland, and Fig.2 is the Marconi Radar S647 part of the system, and these pictures illustrate several points: first, the radome shows the solution to the environment mentioned earlier. The high-performance long-range radar itself operates at both 10 cm and 23 cm in a back-to-back configuration, the 10 cm antenna being optimised for long-range low-angle cover, where close-in clutter is less significant, and the 23 cm provides good overall cover up to high angles, with particular emphasis on good signal processing to remove clutter from weather and terrain. Both antennas are fitted with special primary feeds designed to optimise the antijamming performance.

The naval surveillance radar illustrated in Fig.3 embodies a 10 cm and 23 cm primary radar antenna and a secondary identification friend or foe radar antenna all in the same envelope, and achieves the same purpose of using each frequency in the best way. In this instance, the form of modulation of each radar is also different. The 10 cm element uses pulse modulation with a fairly conventional moving-target-indication system, giving excellent air and surface cover at longer ranges. The 23 cm radar uses 'pulse-Doppler' modulation, which gives the superior clutter suppression essential to naval usage, but which is more suited to closer ranges, albeit with sufficient sensitivity to detect extremely small high-speed targets, because of the constraints of range ambiguities inherent in a Doppler system at longer ranges.

The method by which frequency is used within the band is important in electronic warfare. In just the same way that the use of two quite separate frequency bands will force an intruder to radiate jamming in both bands, a spread of frequency within the band will force the jammer to follow, and to spread his jamming over a wider range of frequency and thus reduce the power radiated within any part of the band. It is therefore important that the use of frequency as an antijamming measure should be freely available, and a spread of frequencies for the actual function of determining the position of targets is a hindrance in this respect.

The tactics of frequency utilisation is a major topic in its own right. Although a radar may well be able to shift from frequency to frequency in a random way — known as frequency agility — there is considerable virtue in doing so in groups of successive radiated pulses rather than on a pulse-to-pulse basis, since the former method maintains the necessary high-performance of the signal processors.

It is interesting to conjecture whether in peace time, even if full frequency agility is available, it should indeed be exercised. There is a great deal to be said for single-shot frequency operation except during hostilities. From a security point of view, the element of surprise is essential, and one may not wish to reveal the extent of frequency spread possible until actual hostile jamming is encountered, and, secondly, to avoid interference with other services, both civil and military, which is sometimes referred to in a rather pretentious way as preserving the ecology of the ether.

The first and most important battle against the jammer can be won in the radar antenna. In many currently installed radars, the antenna pattern is such that jamming energy can penetrate the radar virtually through 360° of its rotation. Therefore a poor antenna pattern with relatively high sidelobes and backlobes is very easy to jam. Jamming effectiveness will be restricted to the main beam of the radar if a very good radar pattern can be produced; in special cases, a good radar antenna can be further improved by sidelobe cancellation techniques (and the effectiveness of the latter is directly related to the quality of the former).

Accurate control of the phase and amplitude distribution across the aperture of the antenna is essential to ensure as near perfect a radiation pattern as possible. The best solution is a linear feed; formerly slotted waveguide antennas achieved this objective, but suffered from 'squint', a movement of the angular position of the radiated beam with change of frequency. In the last decade, radars have been produced and deployed with squintless linear feeds made possible from the point of view of economical manufacture by the advances in numerically controlled machining technology.

Fig.4 shows a typical squintless feed that is used in

2 Back-to-back dual frequency long-range surveillance radar, Marconi S647, similar to the one in the radome in Fig.1

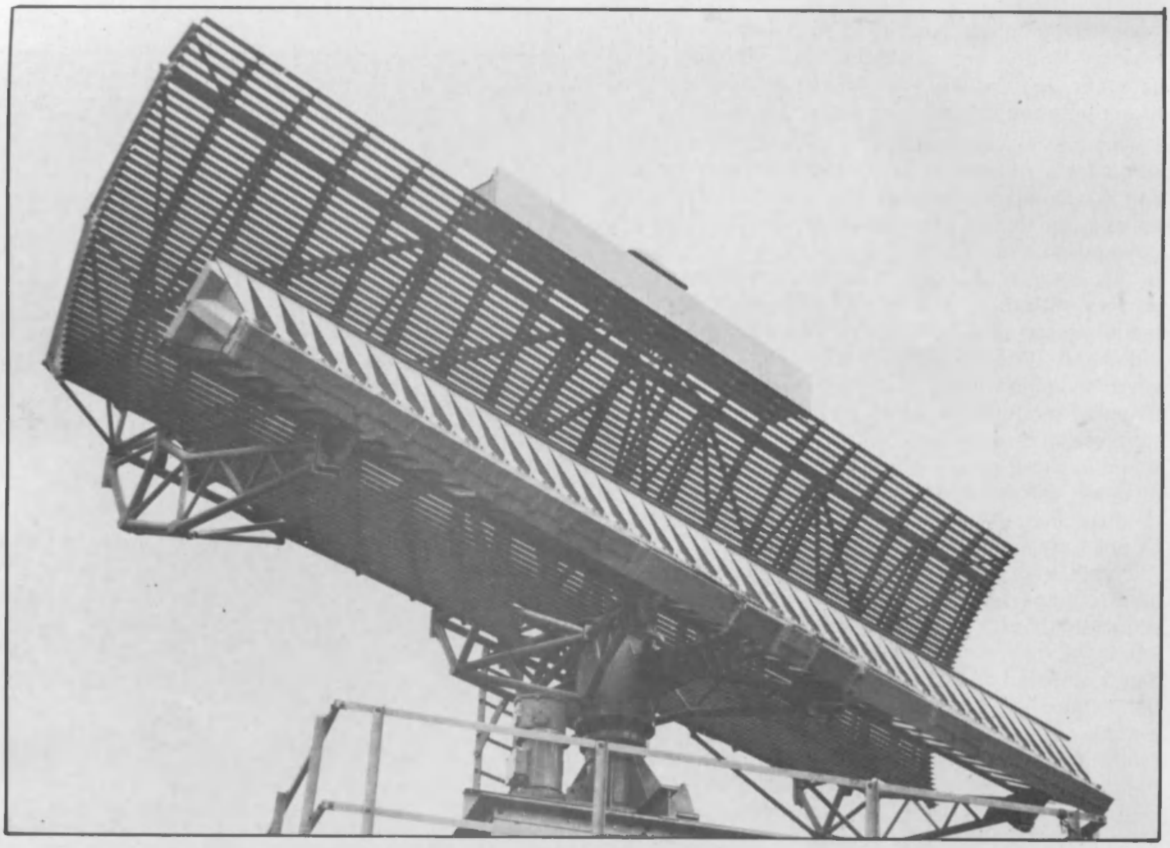
3 High-performance dual frequency naval surveillance radar

the naval surveillance antenna illustrated in Fig.5 and the air-defence radar of Fig.2 already described. For this reason, it is most probable that all future air-defence radars that claim good antijamming performance will have antennas of the 'planar'-array configuration, giving accute control of the antenna pattern, with all reception off the main beam cut down to an absolute minimum. Furthermore, the techniques of precision beam formation from the antijamming point of view will be an important factor in the accurate determination of target position in both azimuth and elevation.

Modern air-defence systems depend on absolutely minimum reaction time to intrusion or attack. In the early days of radar, indeed almost throughout the Second World War, the relative performance of radar and offensive aircraft was such that 30 min warning of attack was not uncommon and 20 min or more was the rule. Today, 3 or 4 min warning could well be the longest one would normally expect, and, with the determined attacker so adjusting his tactics, that a minute or minute and a half might well be all the time available in which to detect and respond. Therefore, there is no time for human processes and mental reaction in the loop, and it is vital to automate the principal air-defence functions, leaving the facility for human intervention available at all times, but only exercised in times of breakdown or confusion.

This starts with automatic extraction from the radar of the instantaneous positional and other data to form plots of all targets in the airspace. To reduce false alarms, i.e. apparent plots produced by the automatic-plot extraction equipment, to an operationally acceptable level, requires a very 'clean' set of radar signals, as mentioned previously, devoid of natural clutter. The removal of clutter is achieved by techniques known collectively as signal processing.

Incidentally, the use of radar reflecting material dispersed from aircraft, called 'chaff' (originally known in this country as 'window'), aimed at confusing radar by producing massive false radar returns, will always be a potential menace. Modern materials



5 New naval surveillance radar embodying a squintless linear feed

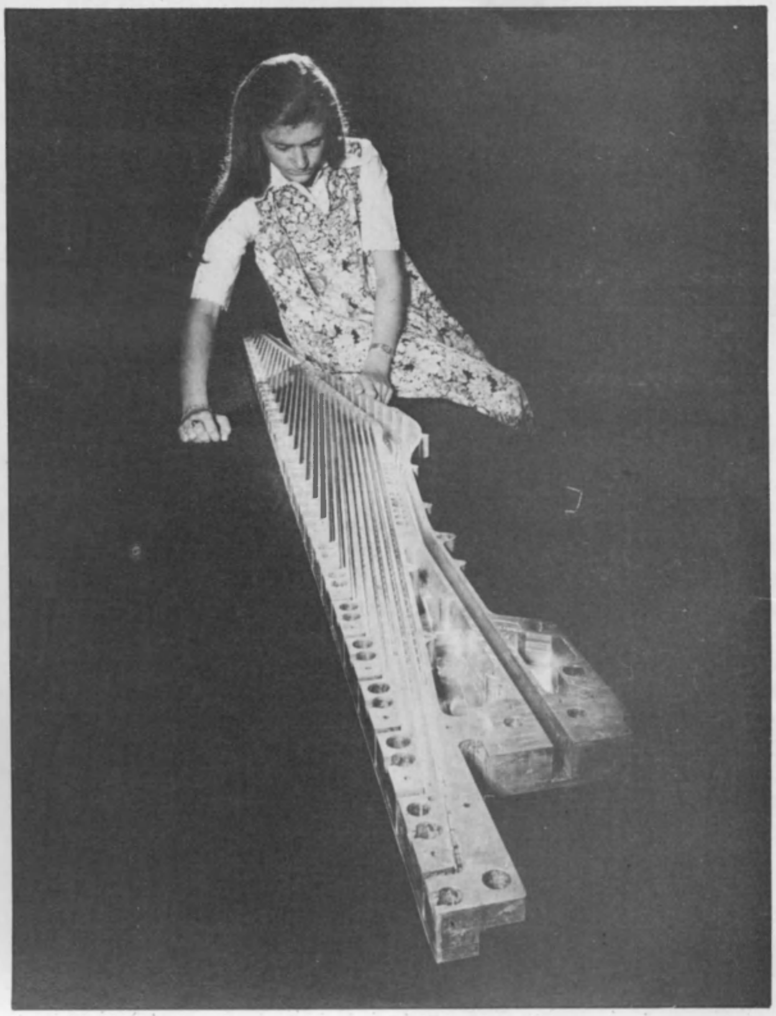
can simulate a very large radar echoing area, blooming to full size in a second or two, from a very small weight of chaff. It is relatively simple literally to 'sow confusion' unless adequate precautions are taken, and the elimination of chaff, man-made clutter, is an additional function of signal processing.

The simpler tasks of signal processing, the removal of impulsive interference, the ability to maximise the dynamic range of the system, and techniques of separating moving targets from static ones in a relatively crude way, have long been available, and, although they have been subject to certain drawbacks, they have worked reasonably well for two or three decades. Well known drawbacks are the loss of targets at 'blind speeds' (certain velocities at which the target is eliminated as though it was stationary) and relatively crude performance in picking out targets from within clutter, known as subclutter visibility.

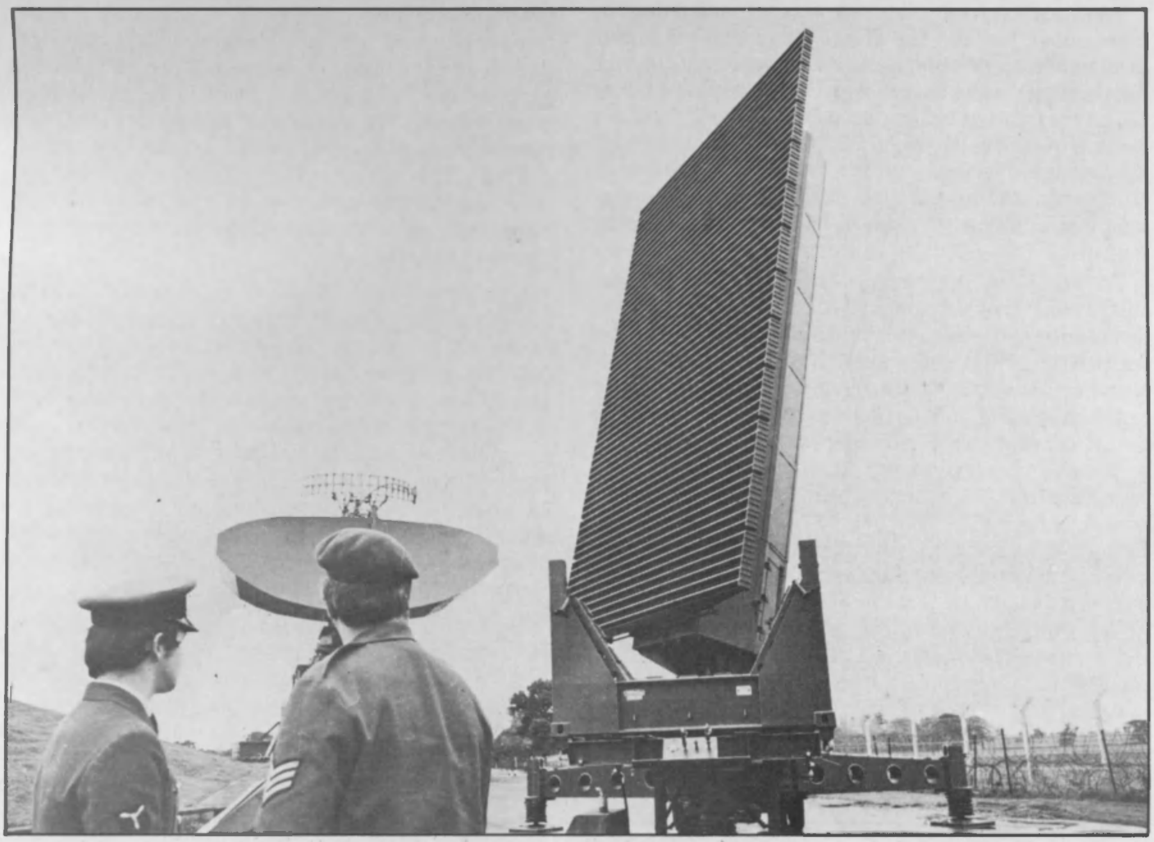
The cheap availability of medium-scale-integration microcircuitry has revolutionised the technology of signal processing and improved its effectiveness several orders with little or no increase in cost. For example, whereas in early systems, one had a single Doppler filter which eliminated zero velocity elements, one now splits up the Doppler spectrum into a number of overlapping bands, and covers each band with a separate filter. Within each filter there is an adaptive threshold which sets itself, as it were, to the optimum level for whatever clutter pattern is observed. Therefore blind speeds can be eliminated and subclutter visibility maximised, whether the clutter be meteorological, topographical or man made.

As an additional benefit, the combination of the 'memorised' threshold settings in the multifilters due to clutter levels encountered can be played out to form a clutter map, which in itself will have operational value.

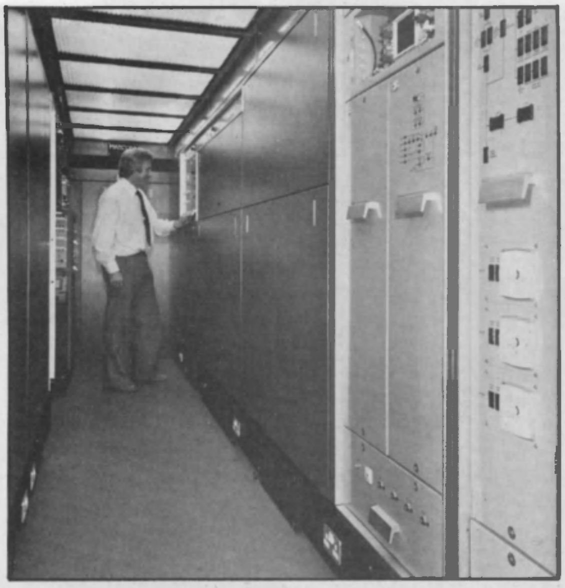
This brief description has only skimmed the surface of modern signal-processing technology, but illustrates the approach to the production of clean radar signals, capable of automatic extraction. A plot extractor, or digitiser as it is sometimes called across the Atlantic,



4 So-called squintless linear feed: each half is cut from a solid billet by numerically controlled machining



6 The 'old and the new' — the Martello radar with an earlier generation surveillance radar in the background



8 Internal view of the Martello transmitter container

9 Martello transmitter container in environmental test chamber

converts the analogue radar signal from each target to instantaneous positional information in digital form. The greater the efficiency of the extractor, the more accurately will the centre of the target be pinpointed, and once again there have been considerable advances in technology in the last two or three years. The output of the extractor is a stream of plots, representing perhaps substantial numbers of flying targets, and each rotation of the antenna beam produces a new set of plots indicating target movement. Therefore two processes must now take place automatically: track initiation and tracking. The association through computer logic of successive plots from an individual target to reproduce the actual path flown is known as tracking; automatic commencement of such a process by examination of a new plot and associating it with one or more subsequent plots is known as track initiation.

Automatic tracking has been feasible, and indeed in operational service, for about 20 years, but cheap availability of reliable storage and processing power has brought about significant improvements in performance and increases in sophistication. Modern systems will track, multiple rapidly manoeuvring, high-speed targets under extremely difficult conditions, and provide full information to the data-handling equipment at the heart of the operational system.

To complete the survey of modern air-defence equipment, it is appropriate to see how the various techniques and philosophies described so far can be realised in actual equipment. Martello is a modern high-performance three-dimensional antijamming radar developed under private venture funding. Its design concepts were evolved by a management team to provide the best answer to world market requirements for the 1980s and onwards. We attempted to strike what we considered to be the appropriate balance between price, overall cover in 'quiet' conditions, jamming performance and transportability. Particular emphasis is laid on resistance to jamming, perhaps more so than is current practice in specifying today's requirements, because of an awareness of the rapidly growing sophistication and power of offensive jamming and a firm belief that future operational requirements will place over-riding emphasis on e.c.c.m. capability. Martello provides in a transportable configuration the sort of performance that has hitherto only been possible in large static installations, in the awareness of the tactical necessity to redeploy one's major radar sensors to new positions at very short notice.

Martello operates in the 23 cm band, and has complete freedom of frequency utilisation within that band, unhindered by the necessity to use frequency for determination of target position, or for any form of scanning process. The antenna is a planar array of 6 by 10·7 m, made up of 60 horizontal elements, each of which is associated with an individual receiver, thus ensuring an enormous dynamic range, and very slow degradation in the event of damage or failure of receiver channels.

Azimuth position is determined conventionally from the rotation of the antenna. In elevation, the output of each receiver is fed to a beam-forming network at intermediate frequency, and within the network a pattern of individual vertical beams is synthesised. This pattern can be very simply changed, but the standard approach is to form eight overlapping stacked vertical beams, each increasing slightly in beamwidth relative to its lower neighbour, the whole being optimised for maximum accuracy of height finding at all ranges. A cosecant squared beam for good overall surveillance is overlaid on the stacked beam pattern. The transmitter pattern in the vertical plane is adjusted to envelope the stacked beam receiver pattern. The antenna has excellent sidelobe performance, several orders better than many previous equipment, thus ensuring fundamentally good anti-jamming capability.

The transmitter itself consists of a high-powered travelling-wave-tube klystron hybrid output stage so driven as to provide all the frequency capabilities described earlier in this article, and the receivers, signal processing and plot extractors embody the latest technology to provide maximum subclutter visibility under all conditions. A radar management position, backed by a powerful computer, optimises the radar output at all times by selecting automatically, but under the supervision of an operator, the optimum parameters under all conditions of climate, terrain, operational exigencies and electronic warfare.

Performance assessments have been made under the most realistic conditions. For example, one could provide improved performance at relatively low cost by the use of extra-low-noise-figure receivers, but at the first whiff of jamming, this apparent advantage is wiped out. Martello really does reflect the technology and the philosophy of optimum performance in the worst environment of electronic warfare. Its designers believe it has all the desirable virtues required of a modern air defence radar, but none of the associated vices!