Air Traffic Control Radar Systems

Radar Systems

Marconi Radar Systems, at the centre of air traffic control radar design and development for more than two decades, has supplied primary radar for approach, terminal area, and long-range control to most of the world's major air traffic control authorities. The Marconi range of air traffic control radar systems meets all the exacting demands of modern high speed air traffic in the face of every problem of weather or location at the world's busiest airports, and on world air routes.

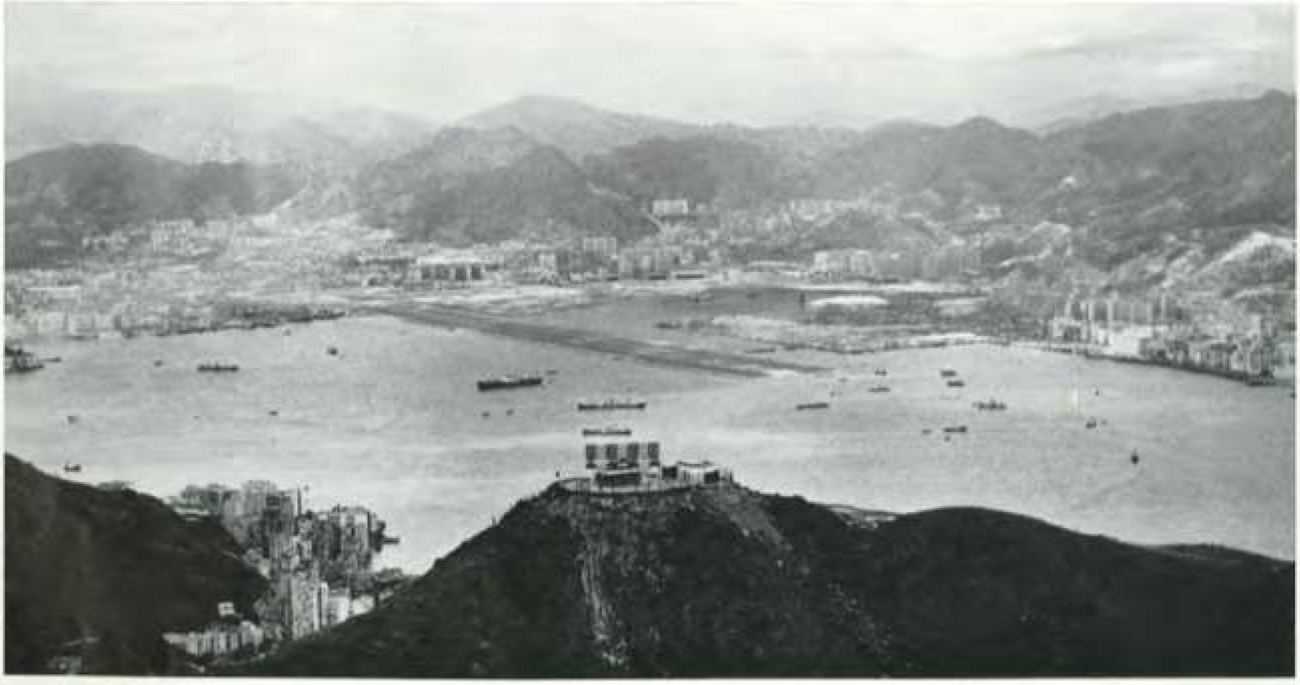
As the only ground-based means of establishing an aircraft's position without its co-operation, primary radar will continue to be used alongside secondary radar and data-links.

To provide approach, terminal area and en-route control from separate radars involves high capital cost and multiple problems of training and maintenance. A multifunction radar, but without unacceptable compromises, is both a desirable and more practical solution.

Marconi Radar Systems has produced two such radars, the S650 and the S654, which meet the needs of both approach and outbound control, and terminal area control in a single equipment. Each of these radars, in a slightly different configuration, can also be used without compromise for terminal area control and en-route surveillance. Both radars use a set of flexible system elements, with options that meet individual operational and technical requirements, without the need for additional development work.

The Company has proved this system concept after prolonged studies of international requirements, and by drawing on its many years' experience of satisfying the demands of air traffic control authorities the world over. There are now fifty-eight Marconi air traffic control radars at forty-eight locations monitoring traffic in countries throughout the world.

One of the world's difficult radar sites – Hong Kong airport – overlooked by Marconi 50cm Band ATC radar (by courtesy of the Civil Aviation Department, Hong Kong Government)



System Philosophy

Operational parameters

The parameters of any radar system are constrained by physical equipment limitations and by the use to which it is put. Conflicting requirements of clutter suppression, discrimination, minimum detectable target, and range must be balanced against choice of wavelength, rotation rate and aerial size.

Radar roles

For an approach and outbound control radar, the most significant requirements are high data rate and good clutter rejection. To achieve satisfactory performance a rotation rate of 15 rev/min, a range capability of 75/111km (40/60 nautical miles) and beamwidth of between 1·5 and 2·0 degrees are typical values required, leading to a high p.r.f.

Because of the short range and low elevation cover required, ground clutter is likely to be severe, making high demands on the MTI system. The condition may be alleviated by using an aerial which delivers the highest possible signal/clutter ratio to the receiver.

For a terminal area control radar, the same requirements exist, together with a need for increased range and elevation performance, typically 185/222km (100/120 nautical miles) range and height cover for overflying aircraft. The range requirement means a reduced p.r.f. and hence an increased demand on the MTI system. For the elevation cover, an aerial with a steep back angle is required, without serious loss of forward gain. An additional requirement is for good suppression of angel clutter.

For an en-route surveillance radar the most significant requirement is long range cover at low elevation, the limit being set by earth curvature, for example, 314km (170 nautical miles) for an altitude of 6100m (20 000 feet). This reduces the possible p.r.f. to an even lower value and some reduction in data rate is inevitable in order to maintain good MTI performance. Also, higher transmitter powers have to be used, particularly at the shorter wave-lengths and this carries the penalty of increased precipitation clutter.

Thus, for the radar to fulfil all these roles, its elements must meet very broad requirements.

For the aerial

Narrow beamwidth for good discrimination
High forward gain to minimize transmitter power
Sharp bottom profile for good ground clutter rejection
Steep back angle for high cover
Good low elevation profile for long range cover
Good rejection of precipitation clutter
Physical design compatible with fast rotation.

For the transmitter/receiver

High stability for good MTI performance
Power output sufficient for long range performance
Low receiver noise figure for good range performance
Wide range of pulse lengths
Wide acceptance of p.r.f.

For the signal processor

MTI performance which does not set the overall system limit
Protection against precipitation clutter
Protection against anomalous propagation clutter
Protection against second-time-round returns
Protection against interference from other radars
Protection against blind speeds
Protection against tangential fading
High stability trigger source

Some of these requirements are mutually incompatible but with careful design, a compromise in one area may be offset by superior performance in another.

Configurations

In addition to performing satisfactorily in themselves, the basic elements must also function efficiently when combined in a system. For example, an aerial head building is usually unmanned and therefore the aerial turning gear, transmitter/receiver and possibly the signal processor must be capable of being fully controlled from a remote site. Turning data and signal data must be in a form suitable for remote transmission. Interfaces must be provided for either a simple display system or a complex data processing system which employs a plot extractor. Compatibility with a secondary radar system, either co-mounted or slaved, is necessary. These requirements can best be achieved by a modular design capable of being built-up as required.

Rooftop aerial installation for a Marconi S650 radar, providing a 140-foot vantage point for Approach/Terminal Area cover at London's Heathrow Airport

Integrity

For satisfactory long-term use, high reliability and ease of maintenance are as important as performance. Reliable operation demands a high standard of circuit components, meticulous quality control during manufacture, and efficient system design. Maximum mean time between failures is ensured by the use of solid-state circuits, high quality materials, comprehensive evaluation and continuous inspection, while regular evaluation and the use of statistical techniques guarantee the long-term performance of the system and its components. However, no component or design can be perfect, and even though standby equipment ensures continuity of service, a fault must be repaired as quickly as possible. Modular unit construction, ease of access, logical equipment layout, built-in performance monitoring systems, and the provision of comprehensive technical handbooks all ensure minimum mean time to repair.

The S650 and S670 50cm Band Radars

As a result of applying the foregoing philosophy, the considerable advantages of working at a wavelength of 50cm led the Company to produce the S650 and S670 radars, the latest additions to a family of radars first conceived in 1954 and now in use in over fifty seven installations in fifteen countries.

The practicability of using a self-coherent system and the unsusceptability to rain clutter enables the 50cm radar to produce clutter-free signals in environments where positive control must be exercised to achieve safe and efficient operation. Typical regions are those with heavy precipitation rates or very mountainous terrain, where the control of aircraft must be precise and continuous Another advantage derived from the wavelength is apparent in a flat-site installation, where the ground-reflected energy may be used to provide increased range cover for en-route surveillance with no change in transmitter power. Exceptional system stability also permits good short-range performance and hence the use of 50cm radar in an approach control role.

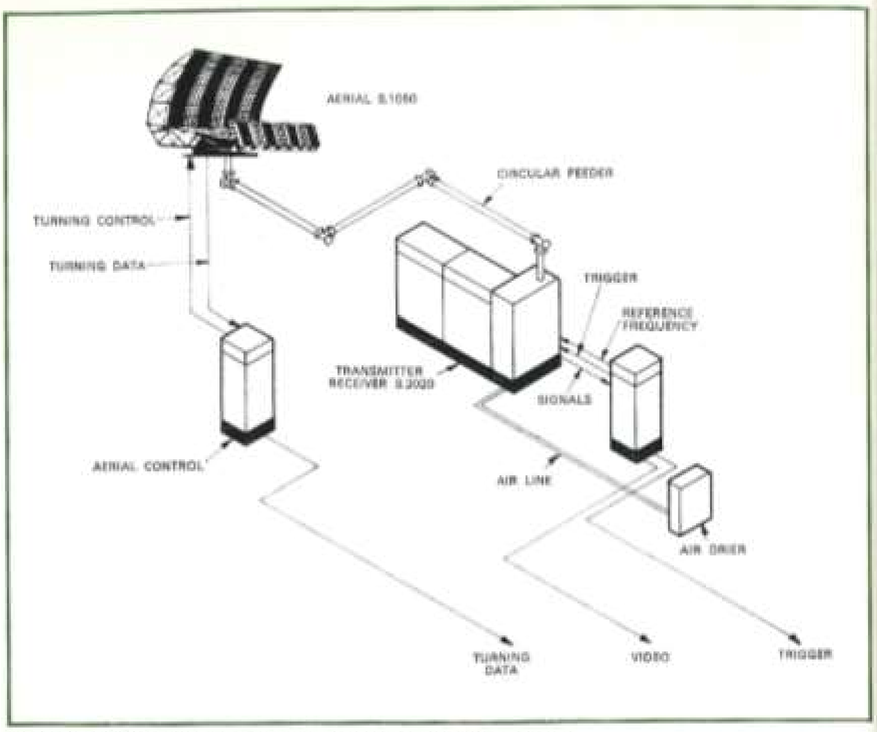
The S650 radar, available in two versions (S650 and S650H) and the S670 radar, use the S2020 transmitter/receiver and the S7100 digital signal processor. A different aerial is used with each radar.

1. S650–S1050 aerial, having a parabolic profile to obtain maximum coverage
2. S650H–S1055 aerial, having a profile to give extra high cover
3. S670–S1070 aerial, having a combination of wide aperture and narrow beam-width to give exceptional range cover

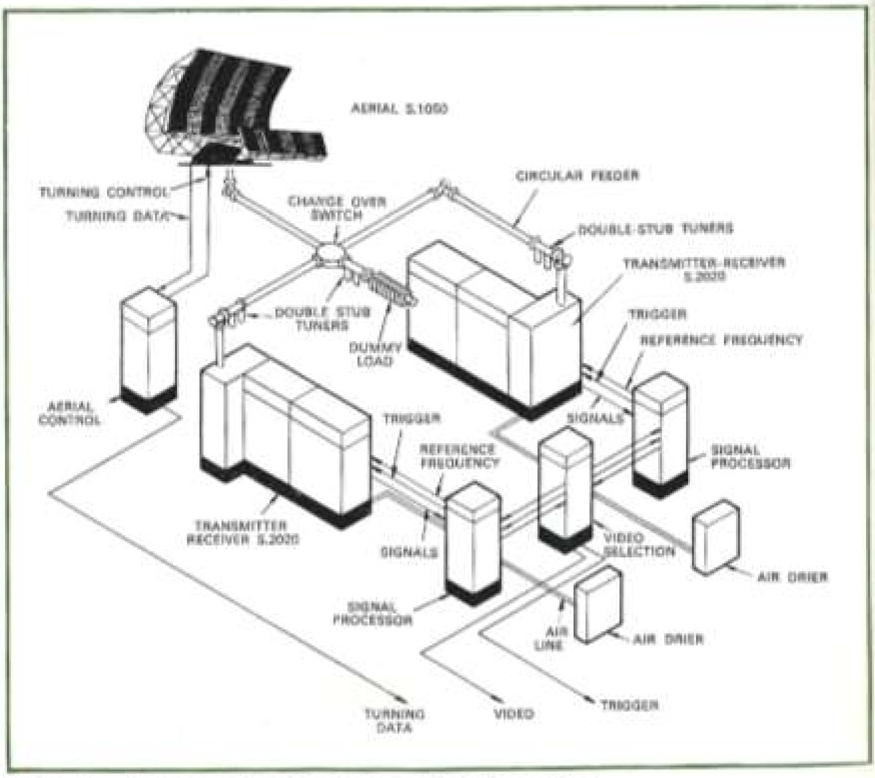
The three aerials are of similar design and use common turning gear.

The aerial design is a single curvature reflector, energized by a slotted waveguide linear feed, with features to ensure good sidelobe performance. The turning gear is located within the reflector/feed structure, allowing a very low mean aerial height. If the aerial is ground-mounted on a flat site, this proximity to the ground in relation to the wavelength means that the lobe and gap structure of the vertical polar diagram, caused by the interference between direct and ground-reflected energy, is very coarse. The first lobe can be used to provide enhanced range cover and the first gap occurs at an altitude above that of operational concern.

The horizontal beamwidth of the aerials S1050 and S1055 is 2·1 degrees and the maximum rotation rate 15 rev/min. In the S1070 aerial, these parameters are 1·7 degrees and 7·5 rev/min respectively.



S650 radar equipment configuration (single channel operation)



S650 radar equipment configuration (main and standby operation)

The S2020 transmitter/receiver employs a crystal-controlled oscillator, referenced to a second crystal-controlled oscillator, to drive a klystron power amplifier which produces the r.f. output. The reference oscillator is also used to derive the i.f. in the receiver and the reference frequency of the phase detector, thus automatically preserving phase coherence. This self-coherent system avoids the need for oscillator tuning and, because the coherent oscillator is fixed in phase, the gradual drift away from coherence as a function of range is not present. This gives equally high quality MTI performance at all ranges immediately upon switching on the transmitter, with no drift during warm-up.

The use of fixed crystal-controlled frequencies also considerably simplifies setting up procedures as there is no need for automatic frequency control devices. Because of the wavelength, an output power of 500kW is sufficient for all purposes. A stabilized modulator ensures maximum pulse-to-pulse stability. The receiver incorporates a low-noise transistor first stage and swept gain amplifier.

The S7100 digital signal processor uses solid-state stores and digital timing circuits, with 8-bit signal quantization, in the double cancellation circuits. In addition, quadrature phase detection is used to reduce the effect of phase notches and to improve sub-clutter visibility.

Also incorporated are:

1. P.R.F. stagger, with easily variable ratios, which substantially reduces blind speed effects
2. P.R.F. discrimination, which eliminates impulsive interference and second-time-round returns
3. A clutter constant false alarm rate (clutter CFAR) circuit
4. A swept gain amplifier which removes clutter due to 'angels', working in conjunction with swept gain amplifiers in the receiver
5. Clutter switching to remove clutter due to residual weather effect
6. Clutter switching to remove ground clutter due to anomalous propagation outside the MTI range gate
7. Video outputs in analogue form for direct connection to local displays and in digital form for on-line linking to a plot extractor.

The new S2020 50cm transmitter/receiver installed at London Airport, as part of the nationwide improvements to Britain's air traffic control radar system being carried out by Marconi Radar Systems

The S1050 aerial at Heathrow

System performance

To illustrate the performance of the Type S650 and S670 radars, the parameters may be fitted into a range calculation equation. Account is taken of the duty cycle, range requirements, system transmission losses, receiver bandwidth, p.r.f. stagger, display collapsing and operator losses and ground reflection effects. All of these factors combine to determine the optimum values of the variable parameters.

The operational parameters chosen are:

$3m^2$ target size
Typical of a modern jet airliner in worst case, i.e. tail-on, or small private aircraft

$10m^2$ target size	average value
Stagger	6 period ±17% maximum
Single look probability	80%
False alarm rate	10^{-6}
Fluctuating target loss	Rayleigh distribution

The fixed system parameters are:

Transmitter/receiver

Wavelength	50cm
Power	500kW
Receiver noise factor	3·5dB

Aerial

Gain	S1050 31dB S1055 30dB S1070 32dB
Horizontal beamwidth	S1050, S1055 2·1° S1070 1·7°
Ground reflection coefficient (two-way)	0·8
Static clutter suppression	40dB

To serve in an approach/terminal area role typical variable parameters are:

Pulse length	3μs
P.R.F	500 pps
Rotation rate	10 rev/min
Aerial tilt	4°
Display range	185·3km (100 nautical miles)

Using a standard calculation, based on the work of Hall, an S650 system gives:

Slant range at 9150m (30 000ft)

Free space:

$3m^2$ target	213km (115 nautical miles)
$10m^2$ target	271km (146 nautical miles)

Flat site:

$3m^2$ target	252km (136 nautical miles)
$10m^2$ target	282km (152 nautical miles)

An S650H system gives enhanced high cover and:

Slant range at 9150 m (30 000ft)

Free space:

$3m^2$ target	163km (88 nautical miles)
$10m^2$ target	204km (110 nautical miles)

Flat site:

$3m^2$ target	215km (116 nautical miles)
$10m^2$ target	250km (135 nautical miles)

These systems have a cancellation ratio of 31dB

To serve in a terminal area/en-route surveillance role, typical variable parameters are:

Pulse length	3 μs
PRF	370 pps
Rotation rate	7·5 rev/min
Aerial tilt	4°
Display range	334km (180 nautical miles)

An S670 system gives:
Slant range at 9150m (30 000ft)

Free space:

$3m^2$ target	237km (128 nautical miles)
$10m^2$ target	300km (162 nautical miles)

Flat site:

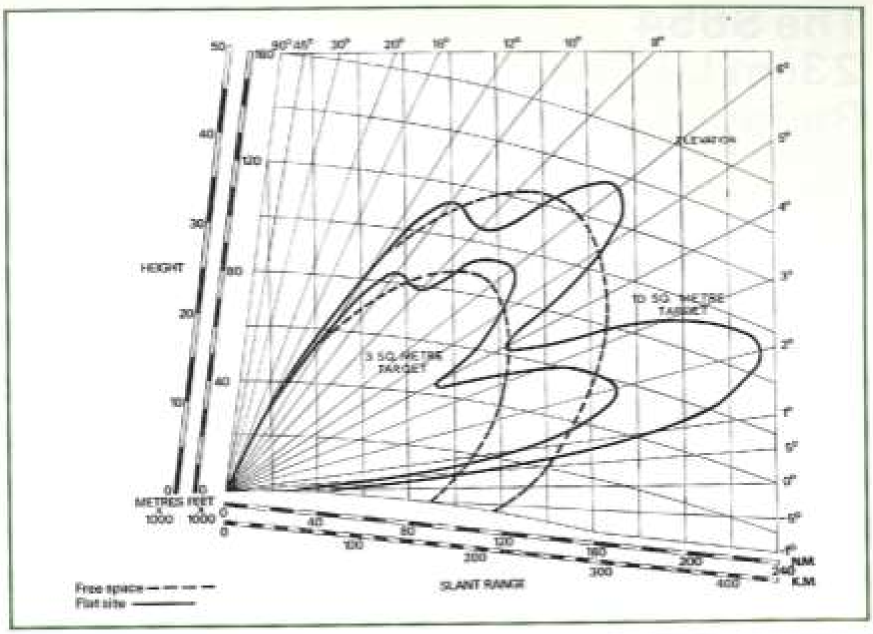
$3m^2$ target	268km (145 nautical miles)
$10m^2$ target	291km (157 nautical miles)

This sytem has a cancellation ratio of 35dB.

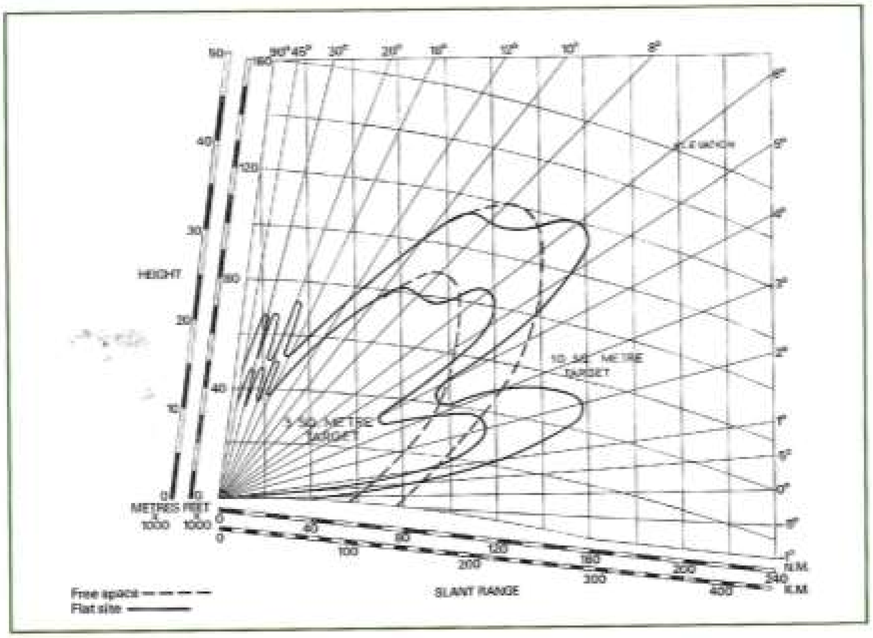
The full cover capability is shown in the vertical polar diagrams.

Full details of the elements of the S650, S650H and S670 radar systems are given in the Marconi Radar Data Sheets listed below:

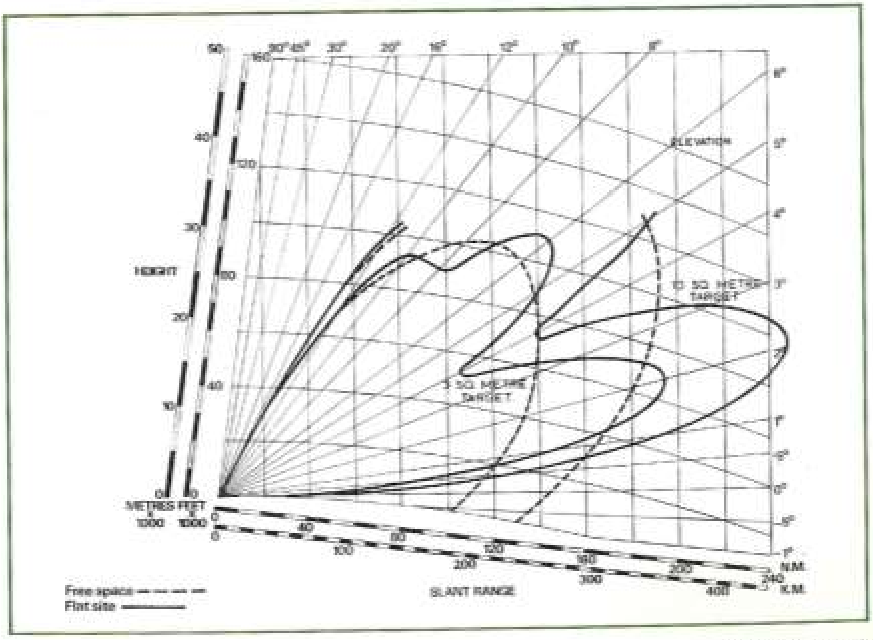
Aerial S1050, S1055, S1070 – data sheet A10
Transmitter/Receiver S2020 – data sheet B5
Digital Signal Processor S7100 – data sheet C3
Aerial Turning Controllers – data sheet E3



Vertical polar diagram for the S650 radar system employing an S1050 parabolic aerial



Vertical polar diagram for the S650H radar system employing an S1055 high-cover aerial



Vertical polar diagram for the S670 radar system employing an S1070 parabolic aerial

The S654 23cm L-Band Radar

For use in areas where there is no frequency allocation in the 50cm band for navigational aids, Marconi Radar Systems has produced the S654 23cm L-Band radar which has a significant improvement in performance over existing equipments operating in this band.

The basic elements of the S654 are:
Aerial S1020
Transmitter/Receiver S2011 or S2021
Digital Signal Processor S7100

The S1020 aerial provides signals as free from clutter as possible to the receiver by using a twin-horn feed. This produces two overlapping beams, one having a reduced gain at very low elevations. Transmission is always via the lower-beam feed, but reception at short ranges is via the upper-beam feed.

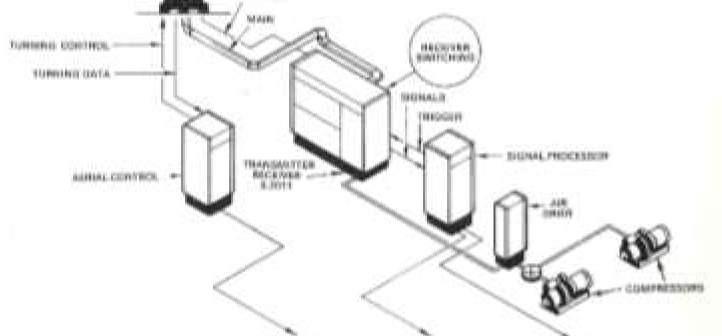
A significant improvement in signal-to-clutter ratio is achieved by the high gain for the transmitted signal in the target direction, coupled with the low gain for the received signal in the clutter direction. Reception via the lower-beam feed gives good long-range cover, as this is beyond the clutter illumination region. The changeover of reception is controlled by a fast-acting r.f. switch, operated at a range chosen to suit the user and the environment.

To provide further protection against weather clutter, circular polarizers are fitted to the feeds. The horizontal beamwidth of 1·7 degrees and maximum rotation rate of 15 rev/min provide good target discrimination and the high stability of the system ensures adequate pulses per beamwidth for the MTI system.

At a wavelength of 23 cm, the best available r.f. power source is the magnetron, but investigation of causes of instability revealed that the magnetron is also the most common source of noise, so a completely redesigned magnetron of exceptional stability has been developed for the S654 system. This magnetron, a new system of tuning to a crystal reference and a stabilized modulator form the basis of the transmitter/receivers S2011 and S2021. The MTI performance is considerably enhanced by the extremely low pulse-to-pulse variations in amplitude and timing, and the frequency accuracy of ±40KHz. An output power of 2·3 MW from the S2011 gives long range cover with a reasonable aerial size. Reduced power of 800kW is available from the S2021, for use in approach control. Swept gain techniques are used in the receiver.

The S7100 digital signal processor uses solid-state stores and digital timing circuits, with 8-bit signal

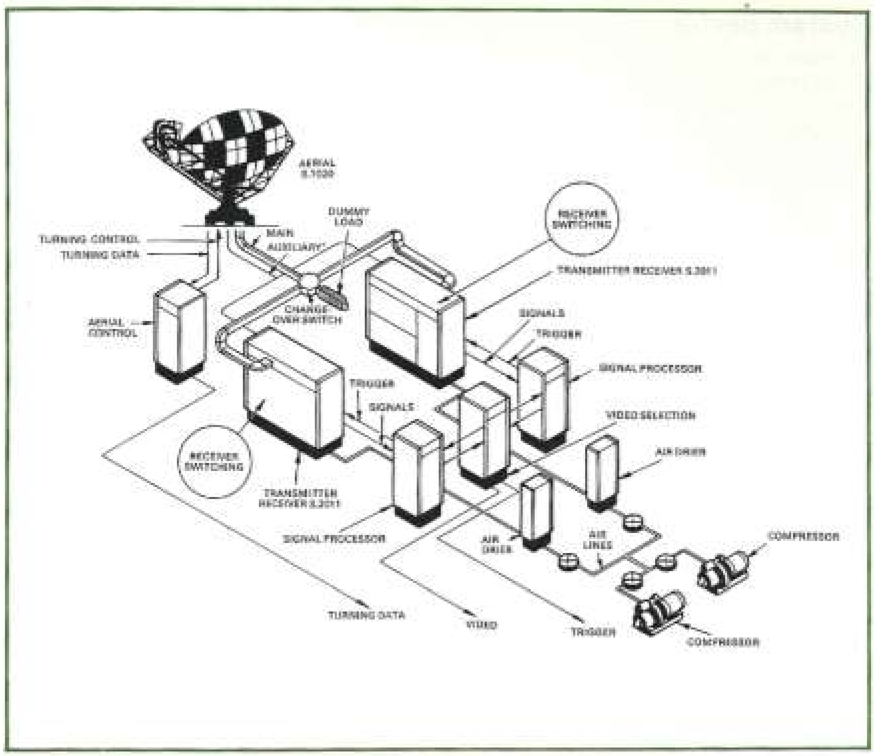
An S1020 aerial installation



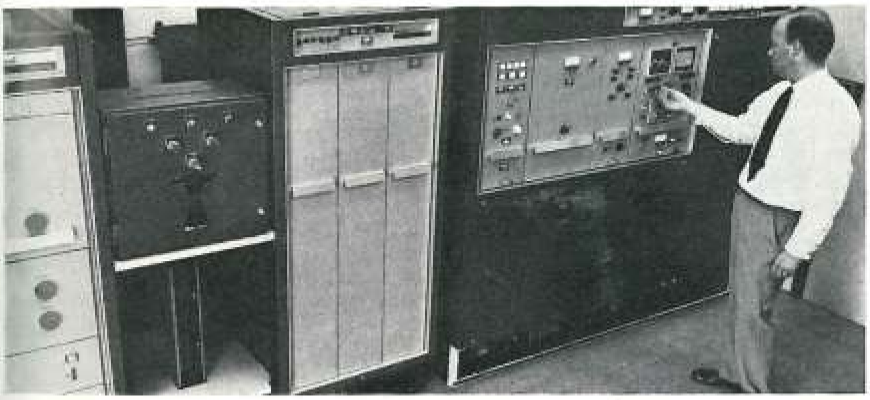
S654 radar equipment configuration (single channel operation) quantization in the double cancellation circuits. Quadrature phase detection reduces the effect of phase notches and improves sub-clutter visibility.

Also incorporated are:

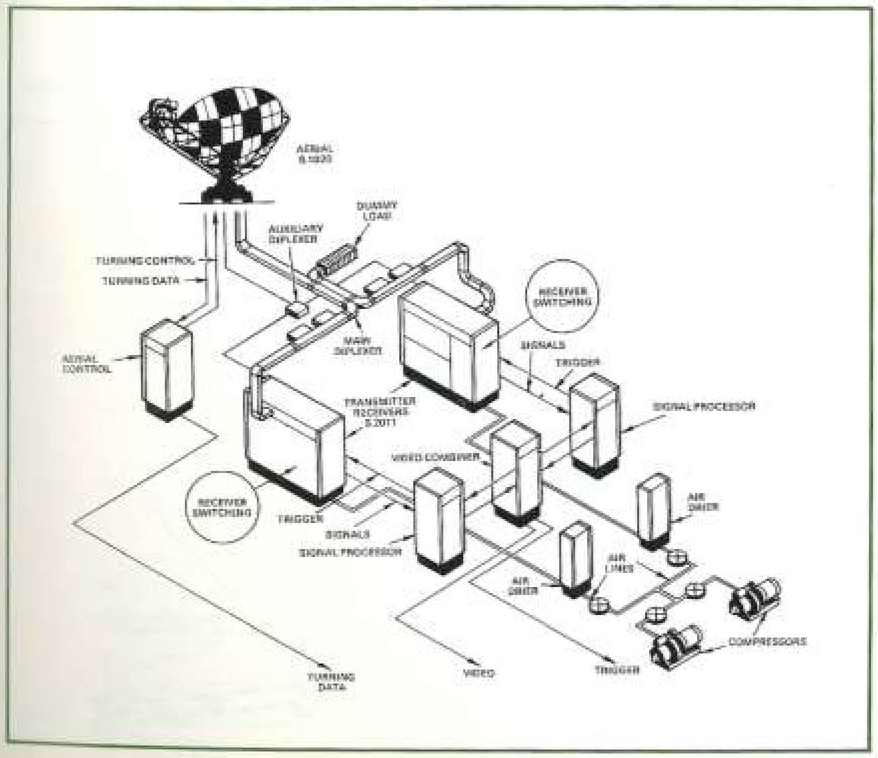
1. P.R.F. stagger, with easily variable ratios, which substantially reduces blind speed effects
2. P.R.F. discrimination, which eliminates impulsive interference and second-time-round returns
3. A clutter constant false alarm rate (clutter CFAR) circuit
4. A swept gain amplifier which removes clutter due to 'angels', working in conjunction with swept gain amplifiers in the receiver
5. Clutter switching to remove clutter due to residual weather effect
6. Clutter switching to remove ground clutter due to anomalous propagation outside the MTI range gate
7. Video outputs in analogue form for direct connection to local displays and in digital form for on-line linking to a plot extractor.



S654 radar equipment configuration (dual channel, main and standby operation)



S2011 transmitter/receiver and S7100 signal processor in a single channel installation



S654 radar equipment configuration (dual channel, diversity operation)

System performance

To illustrate the performance of the S654 radar, the parameters may be fitted into a range calculation equation. Account is taken of the duty cycle, range requirements, system transmission losses, receiver bandwidth, p.r.f. stagger, display collapsing and operator losses, aerial beam shape and atmospheric losses. All of these factors combine to determine the optimum values of the variable parameters.

The operational parameters chosen are:

$3m^2$ target sizes
Typical of a modern jet airliner in worst case, i.e. tail-on, or small private aircraft

$10m^2$ target size	average value
Stagger	6 period ±17% maximum
Single look probability	80%
False alarm rate	10^{-6}
Fluctuating target loss	Rayleigh distribution

The fixed system parameters are:

Transmitter/receiver	
Wavelength	23 cm
Power (magnetron)	2·3MW
Receiver noise factor	2·8dB
Aerial	
Gain main beam	33·5dB
Gain auxiliary beam	31dB
Horizontal beamwidth	1·7°
Static clutter suppression	40dB

To serve in an approach/terminal area role typical variable parameters are:

Pulse length	2·5 μs
P.R.F	590 pps
Rotation rate	15 rev/min
Aerial tilt	3°
Display range	185·3km (100 nautical miles)

Using a standard calculation, based on the work of Hall, a single channel system gives

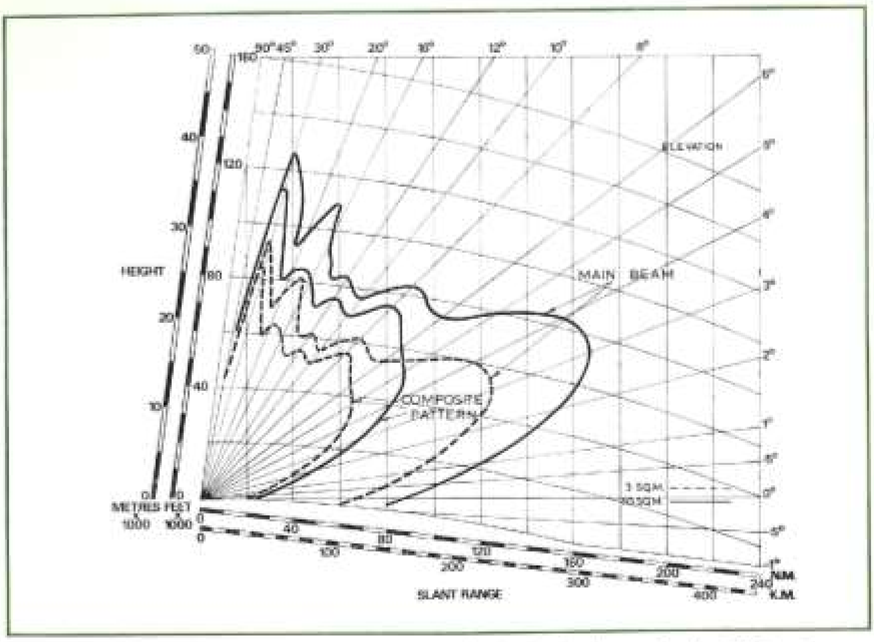
Slant range at 9150 m (30 000ft)
Free space:

$3m^2$ target	204km	(110 nautical miles)
$10m^2$ target	241km	(130 nautical miles)

This system has a cancellation ratio of 31dB.

To serve in a terminal area/en-route surveillance role typical variable parameters are:

Pulse length	4 μs
P.R.F	350 pps
Rotation rate	7·5 rev/min
Aerial tilt	2°
Display range	334km (180 nautical miles)



Vertical polar diagram for the S654 radar system (approach/terminal area role)

A diversity channel system gives:
Slant range at 9150m (30 000ft)

Free space:

$3m^2$ target	278km	(150 nautical miles)
$10m^2$ target	337km	(182 nautical miles)

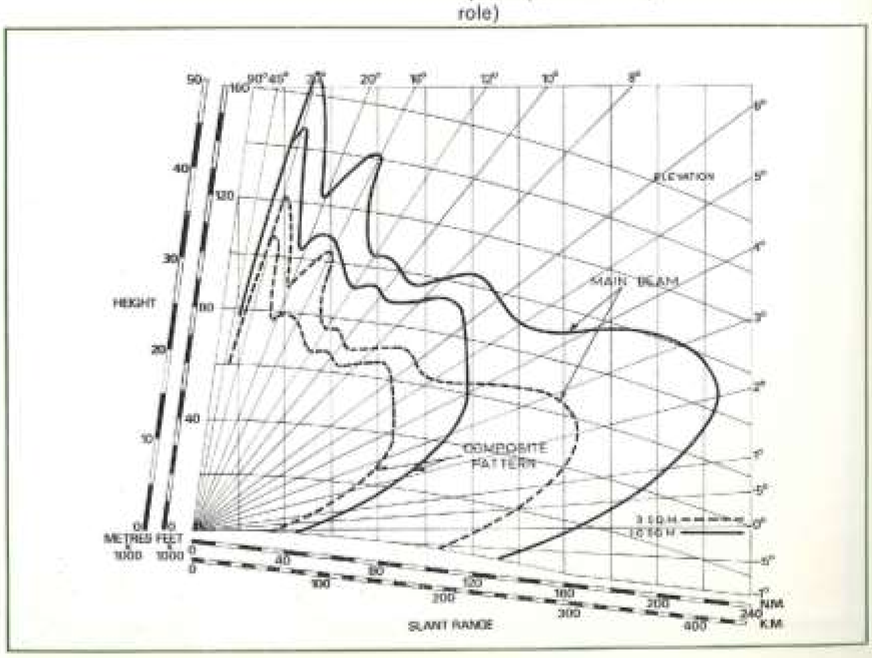
In this case the cancellation ratio is 33dB.

The full cover capability is shown in the vertical polar diagrams.

Full details of the elements of the S654 radar system are given in the Marconi Radar Data Sheets listed below:

Aerial S1020 – data sheet A9
Transmitter/Receiver S2011 or S2021 – data sheet B2
Digital Signal Processor S7100 – data sheet C3
Video Combining Unit – data sheet C7
Aerial Turning Controllers – data sheet E3

Vertical polar diagram for the S654 radar system (terminal area/en-route surveillance role)



System capability

A radar installation may range from a simple local electronics and analogue PPI display system to a full remote dual system, working in a main/standby or diversity role, providing digital data for use in a radar data processing and synthetic display complex.

Complete system capability is provided by a range of accessories and optional equipment which includes:

A waveguide pressurization system
Changeover switches and dummy loads
Diplexers and video combining units
Remote control and telemetry systems
Analogue and digital turning data systems
A monitor display system
Cable or radio links
Aerial towers and no-break power supplies
A digital plot extractor designed to work with the digital signal processor.

In order to provide such complete systems the Company evaluates existing proprietary equipment and, where no suitable unit is available, manufacture a purpose-built item.

Full support services are provided including equipment and system handbooks, spares, test equipment, installation and maintenance services and customer training facilities at the Marconi College.

Marconi Radar Systems Limited offers a turnkey design service for a total installation including site surveys, provision of civil works and communication systems in addition to the radar system itself. Full responsibility is undertaken from the selection of the base site to permanent staffing of the completed installation.

Primary and secondary plot extraction and monitor display system

Challenger Secondary Surveillance Radar System

The Challenger system meets the ICAO specifications in all civil and military modes.

Target obscuration by clutter is avoided by using separate radiation frequencies for the ground-to-air and air-to-ground paths. The ICAO specified performance of the co-operative airborne transponders provides the same radar range and data transfer for all aircraft. The codification on the air-to-ground path permits unique identification of 4096 aircraft in a service area. Altitude encoders permit aircraft height to be transmitted automatically to an accuracy of ±30·5m (±100ft).

System design

INTERROGATIONS

By international agreement and ICAO specification, an interrogation comprises a pulse pair designated P_1 and P_3 radiated at 1 030MHz. The pulse timing defines the Mode of interrogation illustrated in Fig.1. Four modes, A, B, C, and D are allocated for civil use : P_3 acts as the range reference. Modes A and B provide aircraft identification, Mode C provides height data and Mode D is for future use. The pulse pairs have a repetition frequency of not more than 450 per second via a narrow beam scanned in azimuth as in normal radar practice.

REPLIES

If an interrogation passes certain minimum criteria, a transponder automatically transmits a train of pulses in reply at 1 090MHz.

As illustrated in Fig.2 the reply format by ICAO specification, consists of two framing pulses, F_1 and F_2, separated by 20·3 μs bracketing four groups of three information pulses. Range is given by the transit time between interrogation and reply, bearing by the beam azimuth and identity and altitude by decoding the pulse groups.

MODE INTERLACING

The typical beam dwell-time allows for ten to twenty interrogations. Thus identity, position, and altitude data can be obtained in one dwell-time, by alternating the mode between Modes A and C.

Challenger allows any civil/military mode combination to be interlaced by extremely flexible mode programming.

FRUIT AND DEFRUITING

As all interrogators transmit at 1 030MHz and all transponders at 1 090MHz, replies triggered by one interrogator are received by all other interrogators. To prevent range and bearing ambiguities, each interrogator has a unique interrogation rate and the receiver output contains synchronous replies and asynchronous replies, known as fruit.

The Challenger system has a synchronous detector unit known as a defruiter which stores all replies in range order using a separate store area for each current mode. At each repetition of a mode, real-time comparison is made between stored and current data, only the replies at the station's own p.r.f. being allowed into the decoder. All fruit is inhibited since it is asynchronous.

GARBLING AND DEGARBLING

Two aircraft can be close enough in slant range for their replies to overlap in time. This condition is known as garbling. The Challenger decoder system includes degarbling circuits to retrieve the masked data. If two replies are interlaced, full data is obtainable : if open to ambiguous interpretation, the code data is inhibited and only positional data is output.

REMOTE CONTROL

Remote control facilities include system state monitoring with alarms, manual selection and override for most aerial and interrogator/responser functions. Local control may be assumed at any time.

INTERROGATION SIDELOBE SUPPRESSION (SLS)

Aircraft at medium and short ranges can be interrogated by both the main beam and its sidelobes as illustrated in Fig.3. Under these conditions, the azimuth accuracy and discrimination is impaired and fruit generated. An interrogation sidelobe suppression (SLS) technique, specified by ICAO and used on Challenger, overcomes this.

The aerial generates two different radiation patterns, as shown in Fig.3. Pulses P_1 and P_3 are radiated by the main beam and subsidiary sidelobes of the interrogation pattern. An extra pulse, P_2, is radiated through the control pattern at an amplitude exceeding that of the interrogation pair at all azimuths except in the main beam region The control pulse is always 2μs after P_1 for all modes and is of the same duration and output frequency as P_1 and P_3.

The transponder refers the amplitudes of P_1 and P_3 to that of P_2. For P_1, P_3 less than P_2, no reply is made ; for P_1, P_3 equal to or greater than P_2, a reply can be made ; for P_1, P_3 9dB greater than P_2, a reply must be made. The conditions for reply are met only in the region of the main beam. The 9dB 'grey region' covers transponder tolerances.

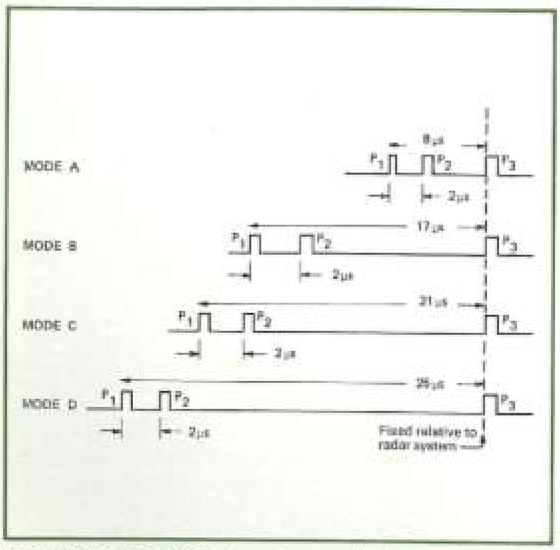


Fig.1. Pulse timing for interrogation modes (transmitted frequency 1030MHz)

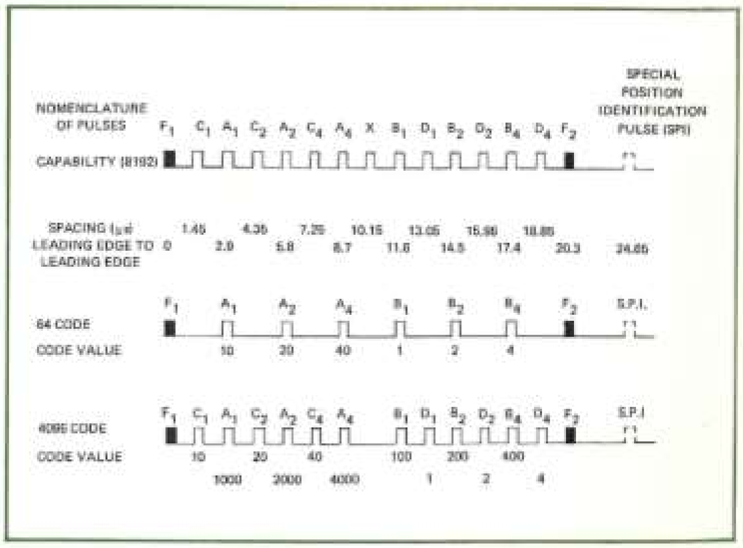


Fig.2. Transponder reply codes (reply frequency 1090MHz)

ACTIVE DECODING
The Challenger decoder produces an output for display registration, giving the aircraft's position. With an electronic marker or a light pen, the operator marks the aircraft position, generating a gate to isolate the marked aircraft replies. These are examined and the mode and code registered as an alphanumeric display associated with the PPI display. An automatic altitude report is given in decimal form in terms of flight level.

PASSIVE DECODING
Expected traffic is allocated a code by air traffic control. With Challenger, the operators can set the decoder to look for correspondence between this pre-set mode and code for all replies. When correspondence is found, a symbol is played out onto the display allowing unique identification. An aircraft can be asked by radio-telephone to identify itself and as a result, the symbol is augmented by an additional response. This is the Special Positional Identification (SPI) feature.

AUTOMATIC DECODING
For fully automatic operation the decoder drives a plot validation unit. This forms returns from the transponder into position, mode and code data for presentation without operator intervention, usually as alphanumerics on a PPI. Multiple mode and code readout, garble and emergency indication are included. Preset controls enable the performance to be optimized for a given environment.

Automatic decoding is usually carried out at the radar head and the output transmitted over a narrow band link.

EMERGENCY AND COMMUNICATIONS FAILURE
The ICAO specification reserves codes 7700 and 7600 for use in a state of emergency or radio communications failure. Irrespective of control settings an EMERGENCY warning is given and the aircraft distinguished by a special symbol. If the radio communication failure code, 7600 is received the same priority is given.

CHOICE OF SYSTEM
The final choice of system is dependent upon many possibilities:

Dual-channel configuration for 24-hour operation.
Integration with primary radar or installation of completely autonomous SSR system.
On- or off-mounted SSR aerial.
Cable or microwave communications.
The need for a defruiter.
Passive decoding in pre-set mode and code combinations or by selection.
Preference for active decoding designation by tracker ball or light pen.
Immediate installation of automatic decoding system if warranted by the existing air traffic system.

System modularity

The system modularity allows expansion of capacity and progression in capability without equipment redundancy.

Expansion by:
Adding a second channel
Increasing the number of operating facilities
Increasing the number of decoding facilities

Progression by:
Converting from manual to automatic decoding
Adapting the unique identification and information source to an ATC data processing system.

Full details of the elements of Marconi SSR systems are given in the Marconi Radar Data Sheets listed below:

Interrogator/Responser S6020 – data sheet D1
Manual Decoding Systems – data sheet D2
Automatic Decoding Systems – data sheet D3

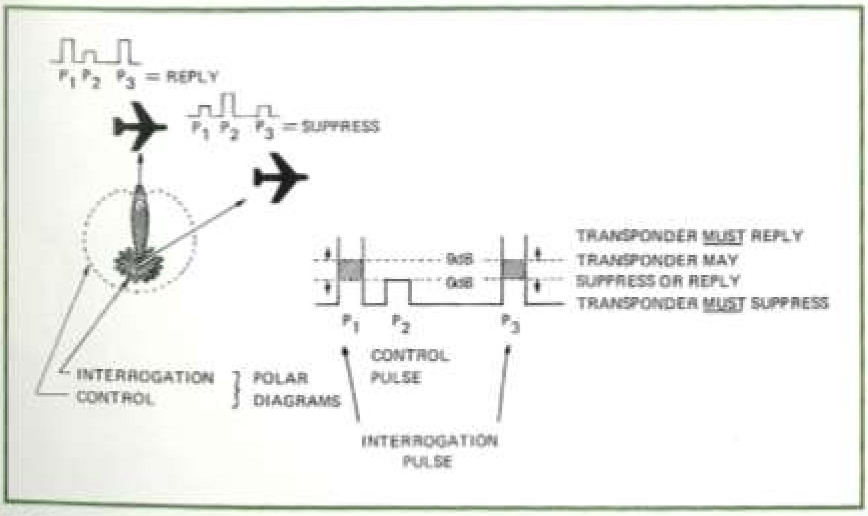
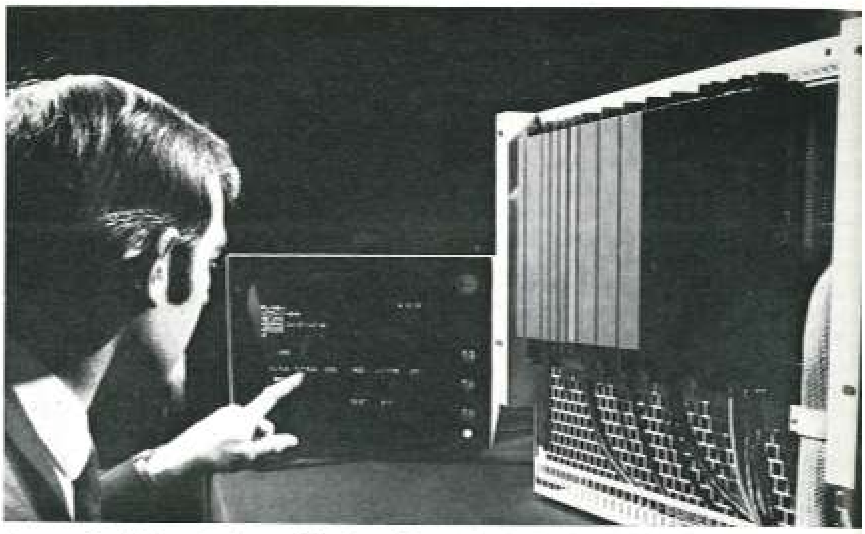


Fig.3. Three-pulse sidelobe suppression – the control pattern covers the sidelobes of the interrogation pattern

A typical display position with selection of SSR facilities

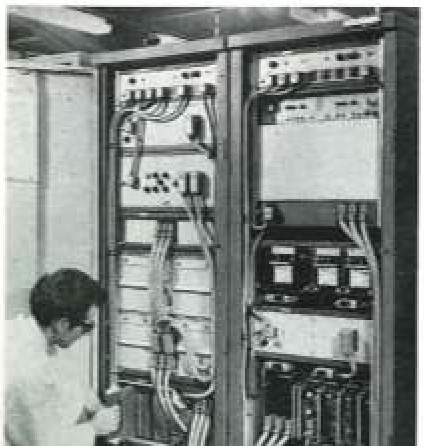
Radar Data Processing


A processing bin from the Locus 16 series, with touch-wire display in the background

As in the first radars, the cathode-ray tube, now much improved, is still the central item of equipment in the controller's suite. Storage tubes and scan conversion techniques have achieved higher brightness levels but still show only raw radar. The increasing amount of traffic in many control centres demands more assistance in interpreting and using displayed information. As visual output using the cathode-ray tube is still the most convenient match to human abilities, more refined data must be provided, preferably using equipment capable of being added on to existing radars in an evolutionary manner.

A considerable improvement comes through the use of secondary radar, which gives aircraft identity and height in addition to position. Manual passive and/or active decoding does not ease the workload significantly and is at best an interim measure. The real benefit is derived by fitting an extraction system to provide automatic decoding. Provided that the radar display is of modern type the addition of the simplest data processing, in the form of storage and character generation, enables the identity/height data to be displayed as an alphanumeric plaque attached to the position plots. This marked raw radar system may be enhanced by the addition of facilities for synthetic map generation, code/callsign correlation and category selection.

The next major step is the addition of further processing power to provide automatic initiation and following of tracks. From this are derived readouts of speed and heading, further reducing the workload and leading to the final procedure of conflict prediction and resolution.


The Myriad III processor and peripheral units

As this system is based on the use of secondary radar it can handle only co-operating aircraft and the display of primary radar is still essential to cover those aircraft either not carrying or with failed transponders. The raw display requires the use of fluoride tubes and hence low-level lighting conditions. As the secondary data is not real time and can therefore be refreshed at a high rate, high brightness tubes can be used and the working light levels considerably improved. Thus to derive full advantage the primary radar also must be in synthetic form, and the fitting of a primary plot extractor is the next step. The primary plots can be accepted and played out by the same data processing system, providing daylight viewing levels. The elimination of the raw radar brings further advantages. Both primary and secondary extractors can be mounted at the radar head. As their output is in digital form only a narrow band transmission system, such as telephone links, is required as opposed to the wide band microwave system required for raw video. This eases the positioning of the radars and makes economic the remoting of data over large distances to solve hand-over problems. Further economies result if both sets of data are correlated before transmission. The only increase in processing load comes if tracking of primary radar is used, due to the lack of inherent identity in the plot data. Once this fully synthetic system is established, extra facilities or further positions can be added as the system growth demands.

Implementation

In order to achieve this system build-up successfully the engineer needs units of correct type of suitable size for all stages of the equipment fit, with the interface defined at each break-point and software available in modular packages. Marconi Radar Systems provides this capability.

The Marconi S3000 range of displays includes units based on common mechanical and electronic modules designed to present basic or labelled raw radar or fully synthetic pictures, with full off-centring and expansion capabilities, over ranges covering approach control to en-route surveillance. Internal waveform generation provides for a very cost effective first stage requiring only turning and video to drive it. For the full synthetic system a digital interface provides the optimum configuration. Other configurations provide three-colour and rear-port projection facilities.

Data processing and display drive are provided by special purpose units for timebase generation, co-ordinate conversion and data input, and by general purpose equipment including the Locus 16 system, one of a new range of processors evolved to meet the particular requirements of radar systems. Locus 16 uses a network of distributed processing elements matched to individual communication, display, input/output and computing loads. It eliminates the need for large central systems and hence avoids the problems and cost of duplicating equipment to meet reliability requirements.

To be really effective primary plot extraction must give a consistent service as good as the best human controller at his peak performance. This implies very careful matching to the characteristics of the radar and its signal processor. The S7100 signal processor/S7200 extractor interface is optimized and the S7200 characteristics can be set to peak performance for any radar. The S7310 decode unit and S7300 plot validation units accept inputs from any standard ICAO SSR interrogator/responser, cover all civil and military modes and codes, and provide multiple code processing, degarbling and emergency and SPI detection.

The S7210 link buffer accepts parallel digital data from the S7200 and/or the S7300 and provides a serial output to CCIT and Post Office Standards for transmission over telephone circuits. It also provides correlation between the primary and secondary plot data plus system status reports and aerial bearing data.

This equipment which uses 19in mounting will fit into a customer's own consoles and cabinets or into standard Marconi control suites. Full installation design and commissioning services ensure that all ancillary requirements are covered.

System programming involves two distinct tasks. First, the basic packages of operating systems, common sub-routines and test programs involve detailed knowledge of the data processing machine. In the case of Locus 16, the software and hardware were specified and implemented together thus achieving the optimum match. The second task is the application programming. This requires detailed knowledge of the system functions. Marconi Radar Systems has a team of system analysts, experienced in air traffic control procedures, who construct flow charts specifying the required software packages and write specialist routines where necessary. At commissioning stage these men work with the systems engineers to prove the total system function.

To provide the most cost effective solution Marconi Radar Systems has produced a series of standard ATC automation packages, based on analysis of many specifications, known radar configurations and required traffic handling capacity. Using standard hardware and software, minor variations in capacity, functions and facilities can be easily incorporated into Marconi systems. These systems range from simple single-display approach control to multi-console, multi-radar en-route and terminal area control handling hundreds of aircraft: systems which have been tested and proved in service and which represent the most advanced thinking, use the most advanced equipment and are backed up by a sound organization.

Full details of the elements of radar data processing systems are given in the Marconi Radar Sheets listed below:
Digital Signal Processor S7100 – data sheet C3
Primary Plot Extractor S7200 – data sheet C4
Link Buffer Limit S7210 – data sheet C5
Automatic Height Extractor S7201 – data sheet C6
Secondary Radar Automatic Decoding – data sheet D3
Display Equipment – data sheets F series
Data Processing Equipment – data sheets G series

A synthetic radar display with selection being controlled through tabular display and light pen

Flight Plan Processing Systems

The Flight Plan Processing System (FPPS) at West Drayton is part of a plan for automation of air traffic control over southern England being implemented by the National Air Traffic Service. It is built round a Marconi central computer complex that uses the latest types of input/output devices to achieve maximum compatibility between the operators and the system.

Flight plan data, originated by the pilots, is accepted from keyboard and touch wire positions. Meteorological data is also input. Validity checks are continuously applied. This variable data is combined with permanent data defining the air traffic control environment. Flight paths are calculated and presented to the controllers on electronic data displays, and records of these and any amendments are stored for reference.

The system consists of three Myriad I computers, with associated backing disc stores; 59 electronic data displays, 38 of which have associated data entry from either keyboard or touch-wire, and 15 telegraph interfaces.

The design achieves an over-all reliability figure of less than one failure in five years' operation. Flexibility and expansion capability have also been built in.

Central computer complex

The computer complex consists of three identical sub-systems made up of a Myriad I high-capacity computer with 32768 words storage; two disc stores with 4 million words storage; peripheral buffers containing input/output, system state control, timing and inter-computer interfaces.

Fundamentally reliable equipment is used giving maximum Mean Time Between Failures (MTBF) while plug-in sub-assemblies provide rapid replacement, giving a low Mean Time To Repair (MTTR). Interconnection of the three sub-systems effectively multiplies together individual MTBF figures of hundreds of hours, giving a MTBF for the complex of many thousands of hours. One sub-system is chosen as operational and controls the system state. Each sub-system accepts all inputs and performs processing simultaneously. The outputs of each sub-system are compared: if 100% match is obtained, the operational outputs are used; if a mismatch is detected, the faulty sub-system is isolated. If this is the one designated as operational, one of the other two switches in as operational and signals a fault; if a non-operational sub-system is faulty, no changeover occurs but the fault is signalled. The displays are not updated until this checkout is completed.

Peripheral facilities

To achieve a reliability comparable to that of the computer complex, the input/output facilities are designed to minimize and localize failures. Parallel channels connect independently to each sub-system.

Entry keyboards, touch displays and status indicators have one digital scanner per sub-system.

Output data is presented on electronic data displays, individually driven in groups from several buffer stores and character generators, fed from the computers via independent buffers. Thus any failure is localized and the last set of data is not lost. In addition, a standby is substituted automatically for any faulty unit and character generators shared to give data renewal at half-rate as an additional soft failure mode.

Programming philosophy

Each sub-system runs an identical program, the output function control being allocated to the operational one. The program structure works at multiple levels each with its own priority, in addition to the hardware priority system. Co-ordination routines keep the systems in step and check for correct output and, if any discrepancy is detected, diagnostic routines are activated.

A fault control system enables defective equipment to be isolated from the active system with automatic changeover to a standby. Indication of the location and possible nature of the fault is given on mimic diagrams and teleprinter printout.

Operational routines are activated either by the system, from the data held on all flights, or by the controllers initiating a change. All input devices operate in a conversational mode and the system response time is of the order of one-fifth of a second.

The flow of data between the central complex and the peripheral devices is controlled by the data transfer routines which check for accuracy of transfer and activate fault control if a failure is detected.

System monitoring

A comprehensive automatic monitoring system uses the facilities of the computer complex.

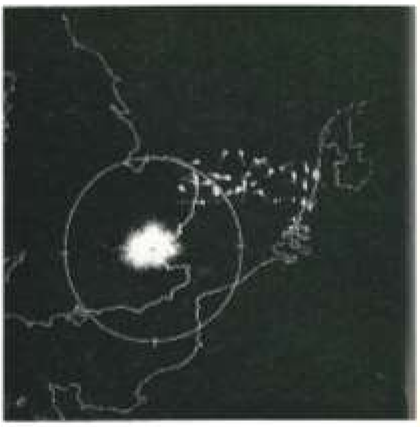
A complete picture of the system state is held in the computer stores. The physical configuration is obtained by tell-back wires. Programmed test routines and hardware checks produce state signals from peripheral equipments, both for operational and standby equipments. Fault detection is followed by program action and the system automatically reconfigures, the new state being shown on mimic diagrams and data displays and fault details printed out. A manual control system assists in rapid location of faulty units and provides an override to the system control either by command via the computer complex or by direct action in the control system.

Full details of the elements of flight processing systems are given in the Marconi Radar Data Sheets listed below:
Display Equipment – data sheets F series
Data Processing Equipment – data sheets G series

The triple Myriad system at West Drayton

The Middle Airspace Control Room at West Drayton

Digital Radar Simulation
Systems for Air Traffic Control Procedures Training



These sequential photographs illustrate the system capability in providing accurate simulation of complex, high density air activity.

From a pattern pre-specified in exercise preparation, the dispersal of tracks is shown on various headings, flight levels and speeds

More than twelve years ago the Company undertook the pioneer work that led to the production of the world's first digital radar simulator. This early success has been followed by a large number of orders for radar-based simulator training systems including equipment to meet the requirements of the UK Civil Aviation Authority, Eurocontrol, the Royal Air Force, and NATO.

Equipment has ranged from site-based training aids, fully integrated with operational facilities, to large autonomous systems for use in training establishments.

The Company's experience of digital radar simulation is backed by more than £2 million of research and development work, and standard packages can be supplied for both hardware and software to produce a system tailored to specific requirements.

Digital simulation offers very much more than just a replacement for earlier analogue training schemes and cannot therefore be directly related to initial cost. The role of the digital simulator is 'environmental', in that it creates realistic working situations for training staff, under essentially operational conditions. In these days of optimum airspace utilization, it is particularly important that air traffic controllers are fully conditioned to working under pressure before this occurs in 'live' operations. The scope of digital simulation is not, however, merely limited to individual controller training, but enables exercises to be conducted at system level with all control elements working together. It is now quite practical and economical to plan for simulation to cover at least 80% of training to qualification standard, with the remaining 20% carried out under operational supervision at the control centre. This presents a complete reversal of formerly accepted proportions.

Unlike other training methods, which to varying degrees require manual intervention, digital systems allow precise exercise 'specification' (which may be exactly repeated if required) in order to obtain assessment of results. Not only can standards be set and maintained for individual performance and team efficiency, but also the techniques employed can be effectively evaluated and improvements made in operational procedures.

System realization

The system is driven by a high speed general purpose computer with a store configuration to suit the particular requirement. This processor interfaces with simulation peripheral hardware of which the major units are the Radar Signal Generator (RSG) and the Aircraft Control Unit (ACU).

The RSG interfaces with the control displays, which may be operational equipment as used in a control centre, or similar in character if specially supplied for a school.

The ACU positions are linked by simulated radio telephone (R/T) circuits to associated control/training positions. The input and output facilities of each ACU allow the operator to deal with all the traffic a controller can handle on one R/T channel. In fully developed training systems, a supervisory position should be incorporated to give full control over the exercise in progress.

Additional facilities such as automatic direction finding (ADF), active SSR decode, flight plan and radar data processing, can be incorporated either initially or as extension packages later.

Simulator output is program-controlled to be consistent with system requirements and operating characteristics. Software packages are designed to deal with exercise preparation, running and recording, replay and analysis.

Simplicity

With any training system, exercises must be simple both to produce and to run. Marconi Radar Systems provides a method of exercise data specification which can be carried out by operationally competent training staff, without the need for specialized technical knowledge. Exercise writing consists of inserting the operational parameters onto special proformas, which are then transcribed onto paper tape and processed by the computer as an off line activity. The output tape is used to run and control the exercise and may be re-run as often as required without further processing. An exercise may last two hours or more, depending upon its complexity and the configuration of processing equipment supplied.

Flexibility

Flexibility is built into Marconi simulator systems, so that changes to operational procedures or equipment can be accommodated without expensive hardware replacement. Normally, it is necessary simply to vary the data produced in the exercise specification and only in exceptional circumstances is a change required in the simulator software. Such changes may be economically carried out as part of the Company's post delivery service.

Modularity in design means that expansion requiring additional hardware is achieved simply by 'plugging in' additional units.

Reliability

Reliability in Marconi simulator systems is achieved by using fully proved processing equipment and special-to-purpose peripheral units, employing advanced technology and manufacturing methods. This in-built reliability avoids costly equipment redundancy in systems which are not required to provide completely 'no-break' services.

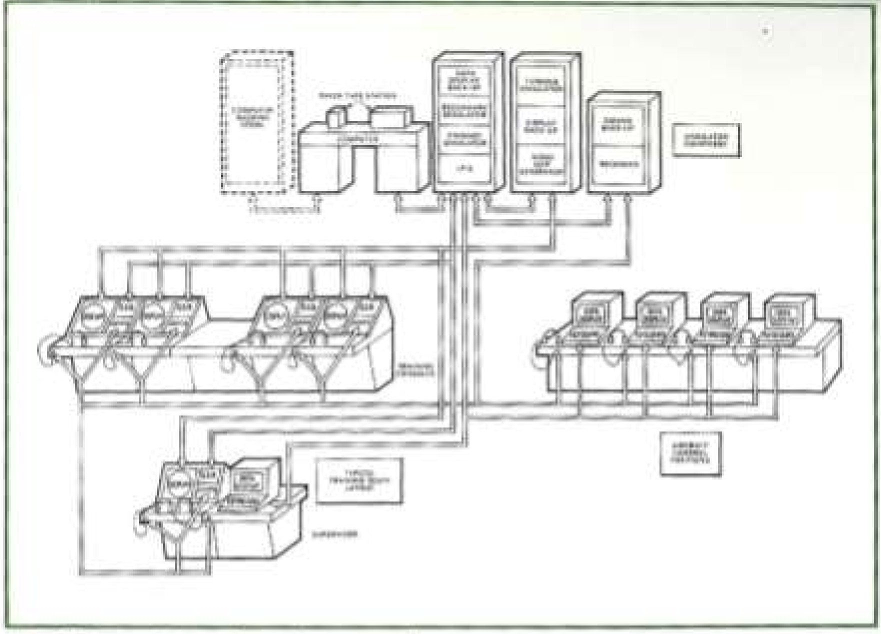
Simulator systems have been developed and supplied for severe climatic conditions and for mobile installation where high reliability must be achieved with minimum maintenance. Maintenance procedures make the maximum use of test equipment which does not require highly specialized technical staff on site. The Company offers whatever technical training or backing in the field may be needed to ensure that the simulator is fully utilized, maintained and developed alongside the operational system.

Customer requirements

Although their existing training facilities may be inadequate, customers are often concerned by the possibility that the modernization of radars, aircraft and ground control systems would render newly acquired training equipment obsolete or inefficient. This is not the case with digital simulation training equipment. The hardware is of a general purpose nature and special effects are produced by program control varied to suit changing conditions, thus maintaining the training system at its maximum effectiveness.

This situation can be fully exploited by the acquisition of a digital simulator before proceeding with a costly replacement of operational equipment. New types of radar can be simulated and their operational effectiveness fully evaluated before cost is incurred. New types of aircraft can be simulated and control techniques perfected in anticipation of the requirement. Control teams can be trained in advance in the use of both new equipment and control procedures, resulting in a much shorter and smoother transition period, providing improved air safety and substantially reducing the cost of training. In activity of this type, and in the course of normal training, provision can be made for voice and digital data recordings which may be analysed immediately afterwards.

The essential feature of Marconi digital simulation systems is cost effectiveness with a high level of classroom training, an inherent capability for equipment evaluation and analysis, and a long in-service life.



Simplified control procedures trainer system diagram

Two trainees at simulated pilots' positions in an S600 radar simulator system

System capability

System capability provides for simulation of:

Primary radar	: 2D, 3D, video, extracted plots
Secondary radar facilities	: Passive/active, video, synthetic
Site characteristics	: Elevation cut off, permanent echoes
Meteorological conditions	: Wind, air temperature
Aircraft performance	: All categories
Aircraft tracks	: Controllable, automatic phases
Airfield activity	: Landing, departure procedures
Navaids	: NDB, VOR, DME, ILS, CRDF
Height finding	: Manual, auto, mode C
Communications network	: R/T, landline
Data links	: Ground air, ground ground
Radar data processing systems	: Automatic, semi-automatic
Flight plan processing	: Strips, dynamic display
Route structure	: SID, STAR, air routes, holding patterns

Full details of the elements of digital radar simulation systems are given in Marconi Radar Data Sheet N1.

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