MMW RADAR TARGET ACQUISITION SYSTEM

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ABSTRACT

This paper describes the hardware and system development which has been carried out in order to evaluate the use of 94GHz radar for the autonomous detection of targets in all clutter backgrounds. Several instrumentation radars, both ground-based and airborne, have been developed for use on field trials. These sytems vary in complexity from simple, solid-state, IMPATT transmitter/Gunn assemblies to high power, pulsed, radars with scanning antennas, dual receiver channels and frequency agility.
The radar concept of interest is one which is carried by a high-speed military vehicle, flying at low level(30-60m), which has to detect and discriminate, with high probability, groups of mobile armoured targets out to ranges of 3Km.

INTRODUCTION

British Aerospace began an evaluation of the use of MMW radar for autonomous target detection and discrimination in 1978. At that time, studies had highlighted the potental benefits of high frequency radar over other sensor technologies, but there was very little practical evidence available. Accordingly, in order to proceed it was necessary to gather data from real targets and clutter using the best instrumentation radars available. Having collected the data this could then be analysed in order to identify potential target discriminants and then effective algorithms. It was understood that the algorithms would identify the parameters needed by practical radar systems.

METHODOLOGY

The methodology adopted was firstly to establish the typical operating scenario of such a Target Acquisition System (TAS). This was performed over many months using operations analysis modelling. Having achieved this, the parameters of interest, such as frequency, antenna size, range, antenna depression angle, scan authority, etc., could be identified. Then, measurement radar(s) were specified and procured for use in field trials. It was expected that initial measurements would lead to the need to develop the measurement radar in order to provide more parameters, different modes of operation, ie. an iterative procedure. There was no positive way of knowing at the start of this exercise which radar parameters were key to good target discrimination and clutter rejection. Also, the component capability at 94GHz, the preferred frequency, was positively infantile in 1978, compared with what it is today. Hence, it was not feasible to specify an all-parameter instrumentation radar set at the outset of this data gathering work.

SYSTEM CONCEPT

The particular radar system concept of major importance was one which could discriminate armoured vehicles when it was carried by a low-flying, high-speed, platform. Operations analysis highlighted the need for a discrimination range of about 3Km on armoured mobile and static target groups, with a cross-range coverage of 3Km. It was also beneficial that the radar should continually scan the ground, rather than lock onto the targets, and that the target should be illuminated for a minimum time.
The scenario was typical European and the radar was most likely to be carried over urban and industrial areas, as well as open, natural, ground.
These requirements led to the choice of a pulsed radar and a low depression angle antenna, the antenna having an elliptical beam shape, a scan angle of +/-30deg. and low sidelobe levels(<25dB). The radar had to have a waveform which would allow both moving and static targets to be discriminated.

INSTRUMENTATION SYSTEMS

Phase 1 (1978).
The first instrumentation system, called Phase 1, consisted of seperate 12 inch Cassegrain antennas, one for transmitting and the other for receiving, with manual linear polarisation switches. A 5-watt pulsed IMPATT produced a fixed 100nS wide pulse at 94GHz. The receiver consisted of a single balanced mixer, fed by a temperature stabilised GUNN L.O.. The I.F. signal was attenuated by a switchable attenuator, amplified, detected and video amplified prior to being digitised and recorded. Fig.1 shows the rear of the transmitter and receiver assemblies.

Phase 1A (1979).
Phase 1A was a modification of the Phase 1 radar which added a twin-channel receiver and

pulse-to-pulse polarisation switching. The twin channels were developed to provide phase and amplitude information, on a pulse-to-pulse basis, over a 35dB instantaneous dynamic range. The two channels carried the linear orthogonal components of the received polarised signal at the antenna. Each channel had a balanced mixer, a PIN diode remotely controlled attenuator, filter, amplifier, a detector and video amplifier. Between the I.F.'s of each channel was connected a phase discriminator, which produced the SIN and COS of the difference in phase between the two channels. Both mixers were fed by a temperature stabilised GUNN L.O..

The polarisation could be switched in linear or circular modes at rates up to 50KHz using a ferrite switch, although accurate settings of polarisation were only achieved at much lower rates.

This radar was used to measure the RCS and polarisation sensitivity of targets and clutter.

Phase 2 (1980).

The large chirp (approx. 200MHz) produced by the pulsed IMPATT source in the above radars coloured the fine detail which was needed. Also, other parameters such as short pulse-widths, frequency agility and coherency could not be evaluated by these two, essentially simple, radars.

In 1979 a specification for a more capable Test Instrumentation Radar was produced, which set the requirement for pulse-widths between 5nS and 100nS, pulse-to-pulse linear and circular switching or fixed polarisation, fixed or agile stepped frequency operation over a defined bandwidth, coherent operation and 64 range gates produced by a directly interfaced high-speed data acquisition and control unit linked to a DEC PDP-11/34 mini-computer. Fig.2 shows the Phase 2 main system components - a remote RF/IF unit, a signal handling and data acquisition unit (centre) and an industry standard digital tape recorder. Fig.3 shows a block diagram of the transmitter/ receiver unit. In fixed frequency mode the system is phase locked to a 100MHz, low noise, crystal oscillator. The phase locking is achieved by comparing a multiplied-up version of the 100MHz with the output from a temperature stabilised 93.5GHz GUNN oscillator. The error signal is used to bias tune the GUNN in order to maintain phase-lock. Although this form of bias tuning control is little used these days, it was chosen as a compromise in order to produce the required amount of frequency agility. Also, after resolving the early teething problems, it provided a very good performance in terms of overall phase noise, and fixed frequency coherent operation to ranges >2Km..

The transmitter consisted of a 2-stage injection-locked IMPATT chain, locked to a sample of the 93.5GHz phase-locked GUNN (PLO). The locking signal was gated using a balanced upconverter, as shown. A fast (<5nS) PIN diode was used to remove unwanted phase/amplitude ripple at the beginning and end of the IMPATT produced pulse.

Frequency agility was provided in the original Phase 2 system by a low frequency digital synthesiser which produced a stepping frequency ramp with a bandwidth of about 160KHz. The stepping rate varied on selection up to 40KHz (the radar PRF). The synthesiser output was multiplied x80 and then applied to the PLO loop discussed above. The final output agile range was about 160MHz. This mode of operation did not maintain coherency on a pulse-to-pulse basis due to the large frequency multiplication ratio.

The received IF signal was filtered, amplified and applied to an in-phase and quadrature detector (I/Q). The resulting two video signal outputs were applied to flash digital converters. The highest conversion rate required was 200MHz!. To achieve this, two 4-bit, 100MHz, converters were sequentially sampled on each I or Q leg, ie. 4 converters in all. The digitised output was then stored in a 128Kbyte RAM memory,and then either transferred to a digital tape, or accessed via the PDP-11/34 computer. The radar, data acquisition, computer and all the support equipment was mounted into a purpose built truck for use in field trials.

The original Phase 2 system, delivered to British Aerospace in 1980, had a single channel receiver, 4-bit ADC's, and a non-coherent frequency agile mode. Many modifications have been made to this system to improve its capability, eg. 8-bit ADC's, improved direct frequency synthesiser providing 64 steps, full dual channels in the receiver to provide Stokes Parameter operation. This latter modification was significant in the amount of effort expended to phase and amplitude balance the two channels from RF to video output. Mechanical modifications have also been implemented to provide automatic antenna step scanning in azimuth and elevation.

Further changes are currently being made. The first of these is to replace the GUNN PLO and frequency agile mode subsystem, in favour of a fixed frequency InP GUNN, locked to a reference source at IF, the output being summed in an upconverter with an L-band signal from a direct multichannel synthesiser. This new 'exciter' subsystem will provide 'coherent' frequency agile operation over 512 steps, fast switching (<5nS) and better reliability than the current units. The second improvement is the installation of seperate, well balanced, mixer pairs. The current dual mixer packages (specially built) do not achieve the cross-talk isolation now needed, because both mixers reside on the same quartz substrate. These latest modifications will provide much enhanced performance benefits.

Phase 2 has provided the majority of the data which has identified target discriminants, and its design has been the forerunner of many radar system concepts in use today.

Airborne Radars

In order to statistically characterise clutter of all kinds, copious amounts of data is needed. The problem with ground-based radars is to find suitable sites which can provide the correct depression angles, and lots of variation of the clutter scene, eg. fields, trees, buildings, urban clutter, etc.. Inevitably, this type of site is very difficult to find - a skyhook is needed. Several airborne measurement radars have been developed at British Aerospace, and are described below.

Airborne Radar No.1 (1980/81)

The first airborne radar was a single antenna version of the Phase 1 radar. It was mounted in an aluminium box which was fastened underneath a Scottish Aviation Twin Pioneer aircraft (1957 vintage), which was ideal for the task since the cabin was large and there were two 18 inch dia. holes in the floor. The mounting was fixed beam, but manually steerable. Originally, a 6 inch lensed horn antenna was used but this was later replaced by a 12 inch Cassegrain antenna with a thin perspex weather/radome cover.

This radar flew in the U.K., Germany, and Norway and collected non-coherent data from clutter and snow. Typically, a clutter run lasted 16 mins., the time for a high-density digital tape to run from start to finish. The major problem encountered was that by the time the 5 watt peak power reached the antenna, via orthomode transducer and polarisation switch, there was only about 1 watt being radiated. This, combined with the need for low angles of antenna depression (1 to 5 deg.), demanded that the aircraft should fly below 150ft. altitude. This was uncomfortable for both pilot and radar operators!

Airborne Radar No.2 (Called Phase 3-1985)

A more capable airborne radar was needed to provide more peak power, scanning of the antenna, pulse width variation down to 10nS and greater range swathe coverage. Such a radar was developed at Warton.

An Extended Interaction Oscillator (EIO) was chosen as the source to provide >1Kw. of peak power for pulse widths between 10nS and 100nS. A scanning platform was suitably modified to give +/-30deg. of scanning at approx. 50deg./sec.. Twin channels of RF and IF reception were built using dual channel 94GHz mixer packages. The RF receiver was mounted onto the twin antenna (10 inch dia. Cassegrains) scanning, stabilised, platform, whilst the transmitter subsystem was mounted off-gimbal. RF peak power was fed to the scanning platform via a length of dielectric waveguide. The length of this cable was approx. 24 inches, and its final version insertion loss was 1.3dB, with a flexure variation of 0.3dB over the angles used.

The dual channels of RF were provided from the output arms of an orthomode transducer connected directly to the receiver antenna. Each channel had a receiver protector using a PIN diode switch providing >25dB of isolation to radar transmitter spillover. Both channels were carefully matched in phase and amplitude using matched components right through to the logarithmic detectors and phase comparator.

The whole of the RF and scanning platform was mounted below the Twin Pioneer, and a specially developed radome and fibreglass cover was used for wind and weather protection. IF receiver circuits, data acquisition and recording and all control circuits were mounted into four 4ft. cabinets mounted within the aircraft. Fig.4 shows the radar mounted beneath the Twin Pioneer.

This system first flew in December, 1985. During the long development period, work using Phase 2 had highlighted the use of frequency agility for target discrimination. This was so powerful that we needed to provide Phase 3 with frequency agility, and with In-Phase (I) and Quadrature (Q) detection.

Phase 3A (1988/89)

Adding frequency agility to the EIO was not an easy matter. This modification was designed by Varian, Canada, suppliers of the EIO subsystem. A triangular format stepping waveform is produced digitally, each step triggered at the selected PRF. This voltage waveform is transformed to a high voltage using several stages of transformer and HV multiplier and is then applied between the EIO cathode and the prime HV supply (20KV). The EIO can change frequency at a 20KHz max. rate, with a useable bandwidth of 160MHz.

In order to maintain a constant IF receive signal an automatic frequency control (AFC) was developed by British Aerospace, which works by sampling the transmitted 100nS pulse to produce an offset voltage to drive the varactor in a GUNN VCO. This GUNN oscillator provides the first L.O. to the receiver mixers. The AGC works well to pulse widths down to 50nS.

In Phase 3A the IF receiver was rebuilt to provide I and Q output channels, for each received signal, instead of the earlier log detection and phase comparator system.

Phase 3A first flew in 1988 and has since been gathering data specific to target discrimination algorithms.

PHASE 4 (Being Developed)

In 1982 investigations began on the building of an MMW radar to fly on a high-speed military aircraft. Specifications were written for the major radar subsystems, radome, antenna, transmitter, exciter, receiver, etc. and these were issued to suppliers. Funding problems prevented further progress until late 1986, when British Aerospace gave the go-ahead. Hardware development work started in mid-1987.

Phase 4 was to incorporate all the discrimination parameters identified, and to be flown to demonstrate performance in a self-contained military aircraft pod. The subsystems were chosen to minimise development risk and cost, but each is purpose built to meet a demanding performance. Fig.5 shows a block diagram of the Millimetric Target Acquisition (MTAS) pod system, including data acquisition, interfaces and control units. The prime subsystems are outlined below:-

a. Radome - 24inch dia hemisphere, made from PEI/Quartz, 6mm. thick. Radome loss approx. 1.5dB.

b. Antenna- 16inch elliptical offset Cassegrain, quasi-optically fed from off-gimbal. Polarisation stabilised as antenna scans and rolls.

c. Transmitter - High gain EIA with PRF=40KHz. Input drive<17dBm, bandwidth>200MHz. Peak power>1Kw.

d. Driver - InP stable amplifier. Output power >17dBm peak, input power<5dBm. Bandwidth>1GHz.

e.Trans-ceiver – Stepping frequency synthesiser at J-band. Multipliers produce 45GHz & 94GHz. Output pulsing via a modulated doubler, giving 80dB ON/OFF . Twin-channel, balanced, protected, receiver with calibration facilities.

f.IF & Video – Twin-channel IF processor and I/Q detectors with auto phase and amplitude balance.

g. Gimbal & Stab. – 4-axis, 5-servo, unit providing scan, pitch, roll, polarisation stabilisation and seperate antenna depression angle variation.

The current status is that items (a) and (c) to (g) have all been delivered, item (b) will be delivered by the end of February, 1990. Testing and integration is taking place and it is hoped to fly the Phase 4 system at the end of 1990. Use of this system, combined with a hardware processor in 1991, should allow British Aerospace to fully demonstrate autonomous mobile target acquisition.

CONCLUSIONS

The concept of an autonomous sensor to detect and discriminate targets from a high-speed, low-altitude, platform has been investigated by British Aerospace since 1978. 94GHz radar has been chosen as a prime sensor for this role. The key to achieving this capability lies in the inherent ability of the sensor to provide many independent measures of target identity. Identifying such measures requires large amounts of real target and clutter data.
Such data has been collected using several state-of-the-art instrumentation radars operating at 94GHz. The progressive improvement in capability of these systems has been possible because of the improving capability of the basic devices and components – to such a degree that it is now possible to demonstrate viable performance of future systems.

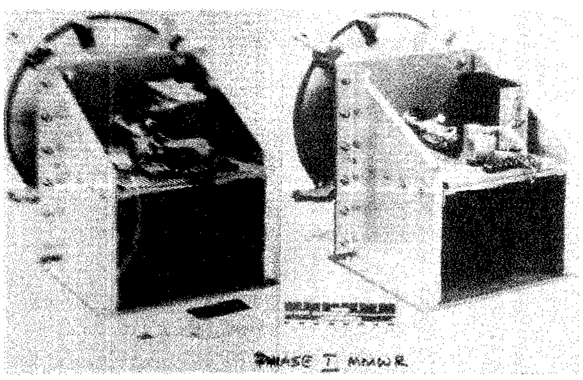

Fig.1 PHASE 1 RADAR UNITS.

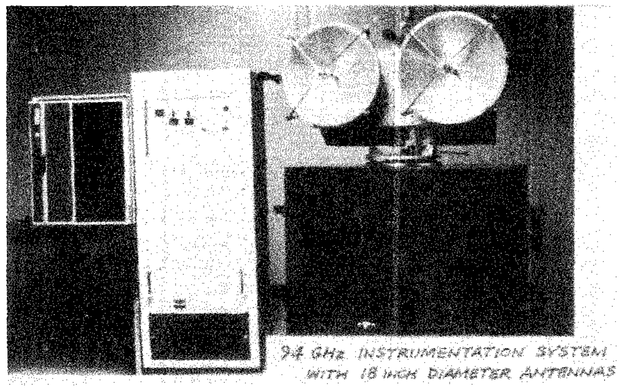

Fig.2 PHASE 2 RADAR ELEMENTS.

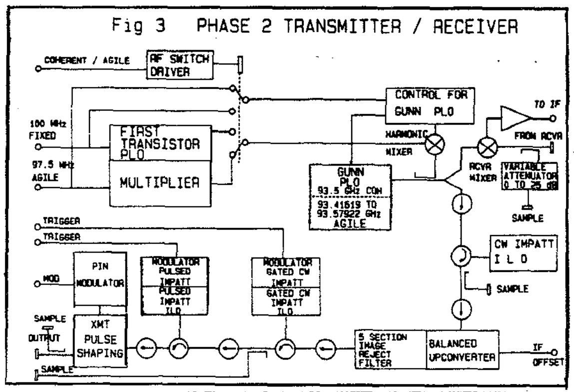

Fig.3 PHASE 2 TRANSMITTER/RECEIVER.

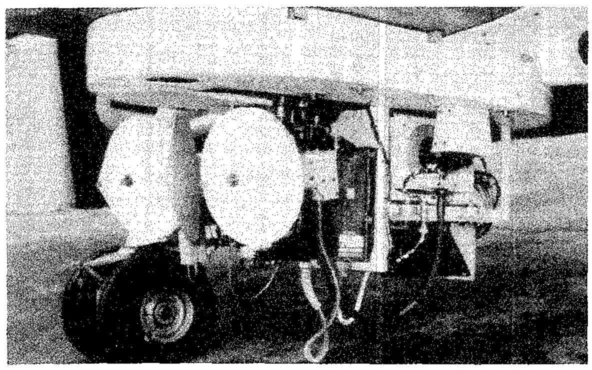

Fig.4 PHASE 3 RADAR MONTED BENEATH TWIN PIONEER.

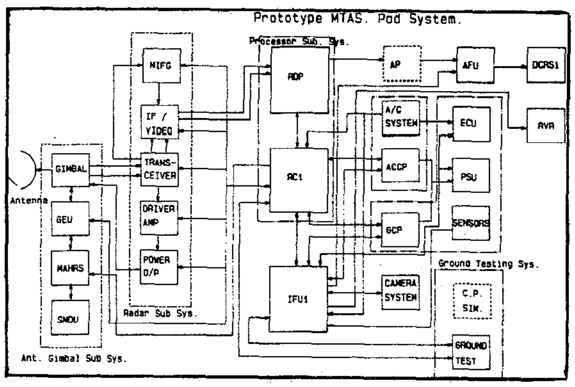

Fig.5 PHASE 4 POD BLOCK DIAGRAM.