The Jindalee Operational Radar Network: Its Architecture and Surveillance Capability

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Abstract - The expansive surveillance capability of the Jindalee Over-the-horizon Operational Radar Network (JORN) stems in part from the ability to centralise control and co-ordination of remote sensors. The two radar sensors are located at Laverton, Western Australia and at Longreach, Queensland, while the surveillance co-ordination centre is situated in Adelaide, South Australia. An extensive communications network will be developed to support the radars and their associated frequency management systems. The principle of operation, configuration and the key architecutral components of the Jindalee project are briefly outlined to provide the context of the Surveillance capability.

INTRODUCTION

The Government Policy information Paper, *The Defence of Australia - 1987*, emphasised the importance of a surveillance capability, particularly over the northern approaches to Australia. It noted the potential of the Over-The-Horizon Radar (OTHR) to monitor the vast expanses of the air and sea approaches to the continent and to provide long range detection and tracking of aircraft and ships. Accordingly, the Government gave high priority to the development of an OTHR network based on the Australian designed Jindalee experimental radar. Jindalee is the outcome of many years research and development in the field of High Frequency (HF) radar by scientists and engineers of the HF Radar Division of the Defence Science and Technology Organisation (DSTO), Adelaide.

The network will provide wide area surveillance of the air and surface approaches to Australia. Information will be integrated with the National Air Defence and Airspace Control System (NADACS) and the Maritime Command Centre command support system. It will also be available for other Australian Defence Force (ADF) and Government users.

PRINCIPLE OF OPERATION

The JORN comprises two remote HF skywave radars and a centralised control centre known as the JORN Co-ordination Centre or JCC. The radars are located near Longreach in central Queensland and near Laverton in Western Australia while the JCC is at RAAF Base Edinburgh in South Australia - see figure 1. In addition to the capability to remotelv contral and process radar information the JCC includes a Software Support and Training Facility (SSTF). The JORN also incorporates an extensive network of beacons and sounders, as part of the frequency management system (FMS), at widely separated sites around the northern coast line, islands and national offshore territories. Although the existing Jindalee facility (1RSU) at Alice Springs does not have the full remote control capability, surveillance information can be passed from the Alice Springs radar to the JCC for integration with information from the two JORN radars.

The principle of operation the radar relies upon the well known phenomenon of long range skywave propagation of high frequency radiation via refraction through the ionosphere. The F layers of the ionosphere, at an altitude of about 300 kilometres, are the main areas of refraction, but the E layer, at about 110 kilometres altitude, can also be exploited in some situations. The HF radiation emanating from the transmitter of each radar is refracted from the ionosphere and illuminates an area of the earth's surface and the volume of airspace above it. Energy is back-scattered from the ground as well as sea, and air and surface targets in this volume are detected by the receiver of each radar.

The JORN radars track using peak detected data which is passed to the tracker in the context of Range, Azimuth, Velocity and SNR. Range information is obtained through sampling of the differential time estimate which result from correlation of the transmitted and the received FMCW *sweep*. The radar's overal range depth is 0.5*c*No. of Ranges(Nr)/Sweep Bandwidth(BW). Doppler or velocity information is extracted by applying an FFT against a *dwell* of FMCW returns in a given region. Therefore the number of Doppler or velocity cells is equal to the number of *sweeps* in a coherent integration period. It is this characteristic of a cumulative aggregation of received returns and the concept of dwelling which distinguishes HF skywave from other conventional radars. Azimuthal information is obtained through beamforming the returns from the 3km long receiver array. The resolution of the radar's finger beams is Wavelength(λ)/Aperture length(D), and a cluster of such

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fine finger beams (Nb) is derived from every dwell to match the energy in the transmitter footprint, i.e. λ*Nb/D. By varying the radar's key operational parameters such as bandwidth, WRF and dwell time, the JORN is able to discriminate and track both air and surface targets at long ranges. The transmitters and receivers will be digitally controlled and are frequency agile.

The location of the two radars has been chosen to complement each other with regard to the effects of skip distance and the observability of targets flying tangential to either radar. In effect, this prevents an intruder attempting to avoid detection by flying tangentially to, or within the skip distance of a radar. At each radar site, the transmitter is isolated from the receiver to prevent interference between the two and protect the sensitivity of the receiver. This isolation is accomplished by separating the transmitter and receiver of each radar by about 100 kilometres so that the ground wave is sufficiently attenuated.

CONCEPT OF OPERATIONS

Command and Control

The Jindalee Operational Radar Network (JORN), is an ADF surveillance asset under the command of the Air Commander Australia, functioning as a Wing within Tactical Fighter Group. Command will be retained at a high level and rarely delegated so that correct priority is accorded to surveillance requests. Hence, command is exercised at the operational level and the OTHR network is tasked from a cell within the National Air Defence Operations Centre of Air Command. Requests for surveillance tasks by various users within the ADF and other government agencies are passed to this tasking cell which then allocates network tasks as shown in figure 2. JORN is a unique surveillance asset, and its integration into the Defence operational environment will surely pose a challenge in terms of data management and the analysis of intelligence.

Robustness is achieved by incorporating into the design a fall-back capability which will allow the receiver and transmitter sites to fall-back into an 'autonomous" mode of operations, in contrast to the normal 'centralised' mode. Thus tasking can be routed either through the Network Management compoent of the Operations Centre during centralised operations or directly to the autonomous operations centre at the remote sites in Queensland and Western Australia. Under this scenario there are up to four possible configurations which will allow continuous surveillance operations to be achieved.

Within the JORN Co-ordination Centre, the operations staff are organised in a hierarchical manner so that tasks are correctly interpreted and prioritised. As shown in figure 2, network tasks are received by the JORN Surveillance Director (JSD) located at the Operation Centre. These tasks are transmitted using a Defence Specified Message Protocol (ADFORMS) and are then translated into specific radar tasks by the operations staff. The network management operator decides on the basis of the coverage region, competing tasks, the state of the ionosphere, and other factors, which radar is better suited for a particular task or, indeed, if multiple radars are required or even if a task can be accomplished at all. When a radar is allocated a task by the network management, the appropriate radar management element in the Operations Centre sets the applicable parameters and controls the radar remotely. This flow of tasking and data can best be seen from figures 2 and 3.

As shown in figure 1, the coverage region of each radar is different. The western radar (radar 2) has a coverage area of 180° whilst radar 1 in Queensland has a standard coverage of 90°. As tasking of OTHR radars with overlapping coverage has not been attempted before, the challenges are unique in terms of overcoming interference, and the tracking of targets in overlapping surveillance areas. It is likely therefore that track fusion techniques will play an important role in development of the JORN.

Each radar operations element comprises an environment conditions adviser, a radar controller, and a number of detection and tracking operators. The environment condition adviser controls the frequency management system and provides advice to the radar controller on the best radar operating parameters to satisfy the tasking requirements. Detection and tracking are automatic but the possibility of multi-path propagation, azimuth and range errors caused by local and transient irregularities in the ionosphere, and changes in target Doppler, may require operator intervention and interpretation. A variety of displays are available for use by the detection and tracking operators to accomplish these functions. The process is very interactive and quite unlike the operation of a conventional microwave radar. For this reason, particular emphasis has been paid during the design to the importance of sound human engineering practice and flexibility of displays and controls and the method of interacting with a largely automated system.

Roles and Tasks

The role of the JORN is to carry out wide area surveillance, that is, the systematic and repetitive observation of large areas at very long range. However, as can be seen from the explanation of the principles of operation, this does not mean that the surveillance is continuous and regular over the whole area of coverage, as is the case with a very large scale microwave radar network. This is neither necessary nor desirable. Rather, the JORN must be considered part of a larger surveillance system which utilises data from a variety of sources.

The output of wide area surveillance is a tactical data base of air and surface tracks. Over time this volatile and perishable information gradually aggregates into a more permanent data base which describes the normal pattern of activity and behaviour in the region. A known capability for wide area surveillance for support of military operations has considerable utility as a deterrent to the use of armed force or to escalation of a conflict.

JORN surveillance can be used directly to support ADF operations. At the operational level, knowledge of air and surface activity in the air/sea gap can be used by the joint force commanders to, among other things, deploy forces, to assign missions to tactical level commanders and provide advice on rules-of-engagement. At the tactical level, wide area surveillance can be used to provide early warning, facilitate asset management, and position forces to best advantage for engagement. The support provided by wide area surveillance is not limited to airspace control and air defence or maritime operations but can also substantially contribute to the operations of other national agencies. Coastwatch, as the national co-ordinating body for surveillance and enforcement operations for customs, immigration, health, quarantine and other government agencies, is expected to be a major user of JORN air and surface track data.

Finally, the JORN is capable of remote sensing of sea state and deriving surface wind data, and measurements of the ionosphere are made routinely as part of normal operations. This information will be used by the Bureau of Meteorology and the Ionospheric Prediction Service.

ARCHITECTURE

The JORN is based on a digital receiver per antenna element architecture. Each element is configured as a doublet to reduce the array's backlobe. This greatly enhances the capability of the radar over lower cost sub-arrayed architectures by achieving more flexibility and full control over spatial discrimination. However the data from 480 digital receivers results in the generation of an extremely large amount of data which must be contained within the receiver site until processing has reduced it to a level where it is cost effective and practical to send to the Operations Centre in Adelaide. The operational need to impose a maximum latency of 3 dwells before the data is available to operators forces a trade off between communications bandwidth and signal processing power. It is this fact coupled with the nature of the data processing which has led to the development of the pipelined architecture shown in figure 3. Each of the three stages has a unique hardware and software solution.

Control of the processing stages and the data streams which emanate from each stage takes place primarily at the receiver site although the high level commands originate from the radar management software at the JCC Operations Centre. Radar management will also undertake all the housework of identifying operators, logging them on, controlling their communications access and the management of the data throughout the network. Of the 26 Computer Software Configuration Items (CSCIs), the Radar Management CSCI is arguably the most important and reflects the architectural structure of the radar.

Processing Architecture

The digital signal processing requirements of the JORN are both fascinating in what they achieve and prodigious in the processing and communications resources they demand [2],[4]. Were it not for the strategic need to develop a centralised Operations Centre in Adelaide then the effects of the signal processing on communications would be minimal as the radar's tracker at each site would reduce data rates significantly, by passing back only confirmed targets to the Operations Centre. Thus a balance has been struck between the cost of providing, maintaining and staffing a larger remote site and the cost of leasing data services.

The JORN processing is implemented as a pipelined architecture, with 3 processing stages and one additional stage being allocated for the transmission of data over the wide area link.

Stage 1, which is located at the receiver site, takes the digitised output form the receivers and carries out the process of beam forming, and range processing. The data output of stage 1 is characterised by clutter and targets returns resolved in azimuth (beams) and in range (Range Bins). The processing load of stage 1 is of the order of 25GFlops.

Due to the high degree of parallelism and low memory requirements of stage 1 a specialised processing solution has been developed around an Intel i860/VME hardware set. The minimum latency requirements imposed by the operational requirements mandate a trade off between data transfer rates and processing power. As processing power is generally more expensive than data rates there is a natural tendency to maximise the time allowed for processing. Integral in achieving a compromise is the development or identification of algorithms and a processing architecture which will allow data to flow between stages while minimising accumulated results, as any delay in passing results in a pipelined architecture results in an exponential increase in data rate between stages. An ideal arrangement is to use algorithms which are able to calculate and transfer data on the fly. This factor has influenced the choice of beamforming algorithms such that in some stages FFTs are less preferable to a sample by sample DFT as DFTs can avoid the latency associated with data accumulation. The beamformer multiplexers of stage 1 clock data out to stage 2 at a bit data rate equal to the WRF*Nb*Nr*Dataword size.

Stage 2 processing can begin the instant the data has been received from stage 1. The small interdwell gap between dwell can be used to transfer results but is primarily used to carry out calibration of the receiver and synchronisation of the control and timing of the radar. Stage 2 comprises around five major processes such as Doppler processing, clutter suppression, signal conditioning, radar statistics, and peak detection [2]. The stage 2 processing would normally be better suited to a scalar/vector architecture, but the high performance scalar machines now available means that similar performance can be achieved directly with reduced level of low level software programming. Stage 2 will be implemented using Commercial Off-the-Shelf (COTS) DEC alpha equipment configured in a parallel arrangement of two processors, where stage 2 of Dwell 1 (figure 3) is processed in processor 1 and stage 2 of dwell 2 is processed in processor 2 and so on. This allows better utilisation of the processors and less risk to the growth path and also improves the communications between stage 1 and 2 and the control software. As shown there is an additional period allowed to transfer the data between stages 2 and 3. Due to the pipelined architecture this period must be less than the length of the minimum dwell period and thus effectively dictates the speed of the WAC link, viz. Size of Stage 2 Output Data/Minimum Dwell time.

Stage 3 (Tracking) is the final stage of processing and is carried out at the Operations Centre in Adelaide. The tracker is required to be robust and to operate in a high clutter environment with ambiguous (WRF induced) and slow moving manoeuvring targets. The tracker algorithm chosen for JORN are based on the work of Colegrove[5] and can be hosted on a standard DEC Alpha configuration similar to stage 2.

Surveillance Architecture

The surveillance area of the JORN is significantly greater than conventional radars. As such, the radar must be able to scan effectively and quickly to meet the revisit times imposed by the tracker and the operational needs of the customers. As a result some specialised features have been incorporated into the design of the radar. It is often the case that single frequency range depth is too small for the surveillance task; hence range stacking at different frequencies is needed (in daytime particularly). JORN achieves this by having the ability to work in half radar mode. This unique feature allows each radar to independently operate with half its array scanning one region whilst the other half of the radar can work independently in both frequency and WRF. This allows extensions of range, if required, by allowing one radar to abut two regions using each half of its radar (figure 1). This feature greatly enhances the ability to extend the radar's range and its coverage area for a given time. There is a potential trade off against a reduction in azimuthal resolution and sensitivity but propagation gains can generally outweigh the Power, Gain and Directivity (PrGtDr) losses.

Survivability

The communications sub-systems must be built around an infrastructure which, in military terms, is survivable. Communications survivability is achieved by a system which incorporates those attributes which attempt to guarantee that a system will not fail due to a catastrophic event within a localised area. Although all of the links will be optical fibre there have been cases of rodent molestation of the cables where fissures have occurred in the soil, especially in far north Queensland. For these reasons survivability has been defined as a communications system which incorporates both diverse path and diverse media. In the JORN this requirement translates into the need for a combination of Satellite and Optical Fibre.

The survivability requirements add to the complexity of the JORN by introducing the need to automatically switch data between diverse services without loss. In the case of satellite services, the increased latency which is inherent in satellite communications by virtue of the transmission delays up to and back from the satellite must be considered. In summary, the incorporation of survivability into the JORN will ensure that only the most catastrophic event will undermine the JORN's communications availability and integrity.

Receiver to Transmitter Intrasite Links

The intrasite link between the transmitter and receiver is used to carry voice, status and tasking data. The radar's isolation virtually means that all services between the receiver and transmitter sites will be purpose built. The control computers at the transmitter facility receive their tasking information from the Receiver sub-system control computers.

CONCLUSIONS

The concept of operations for the JORN is feasible only because of recent advances in communications and processing technology and whilst exploiting the leading edge of technology the project is managing risk and is confident of delivering an initial capability by 1997. The requirements of the wide area communications network for the high speed transfer of radar data in near real time from the remote sensors to the centralised co-ordination centre will be met by the existing or proposed public network to the greatest extent possible.

The delivery of the JORN will provide a substantial improvement and enhancement for wide area surveillance of our vital northern approaches and this success is critically dependent on the advanced communications intrinsic to the operational functionality.

ACKNOWLEDGMENTS

Portions of this work are based on material contained in reference 1.

REFERENCES

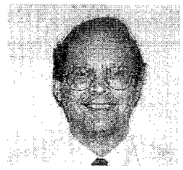
[1] A. Cameron, J. Nicholson, *JORN the Operational Concept*, IEEE Communications '92, Sydney, 1992.

[2] R.K. Jarrott, *The Processing of HF Skywave Radar Signals*, ICASSP International Conference, 19-22 April, 1994

[3] D. Netherway, G. Ewing and S. Anderson, *Reduction of Some Environmental Effects that Degrade the Performance of HF Skywave Radars*, IEEE (ASSPA 89), Adelaide 17-19 April, 1989.

[4] R.K. Jarrott, D. Netherway and S. Anderson, *Signal Processing for Ocean Surveillance by HF Skywave Radar*, ibid

[5] S.B. Colegrove, *Multitarget tracking in a cluttered environment*, Proc. 1987 IASTED Int. Symp. on Sig. Processing and Applications, Brisbane, Australia



Alex Cameron was born in Scotland, on November 18th, 1947. He received his BE(Comms) degree from the Royal Melbourne Institute of Technololgy, and M.Eng.Sc from the University of NSW in 1982. He been involved with the Jindalee OTHR programme since 1986, first as a Naval Liaison officer within HF Radar Division at DSTO and then as project engineer and project authority for the upgrade of the experimental radar at Alice Springs before leaving the Navy to join the Telecom Jindalee team in 1989. His interests include, programming and investigation of signal processing techniques, as well as recreating period furniture. He is presently the JORN Technology Development Manager within the Telecom Jindalee project.

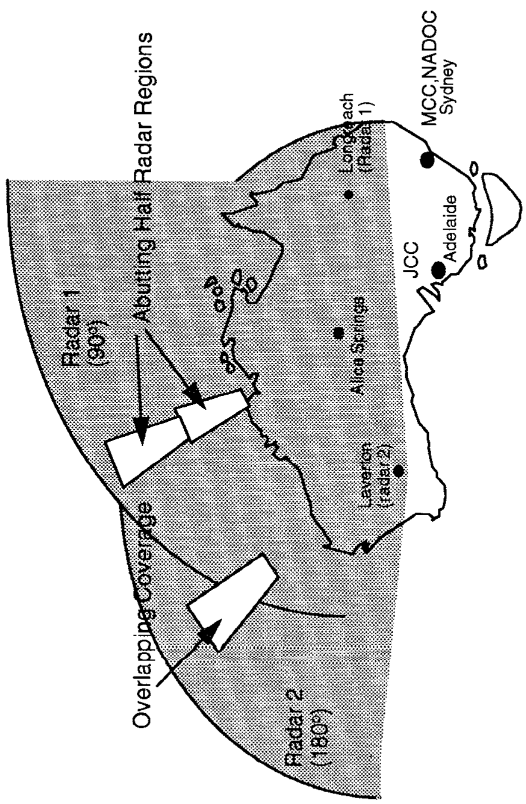


Figure 1: Operational Network Surveillance Coverage

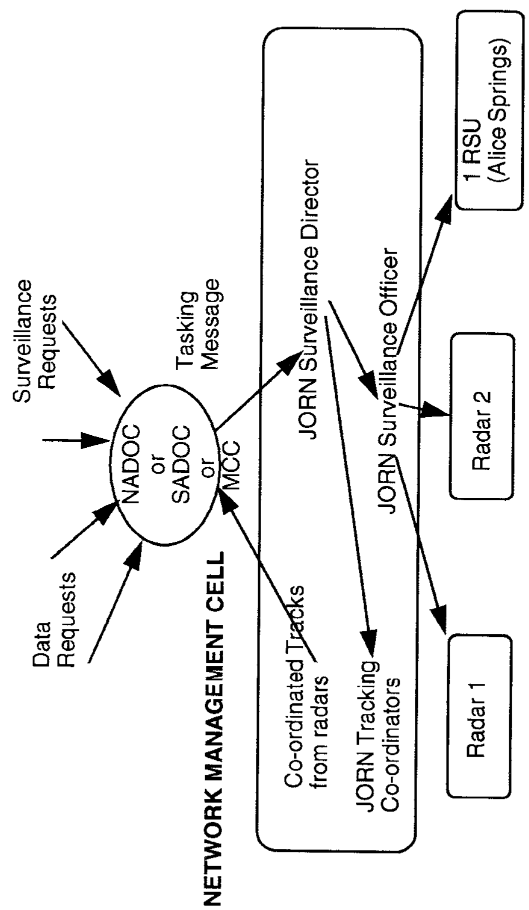


Figure 2. Internal Tasking Information FLow

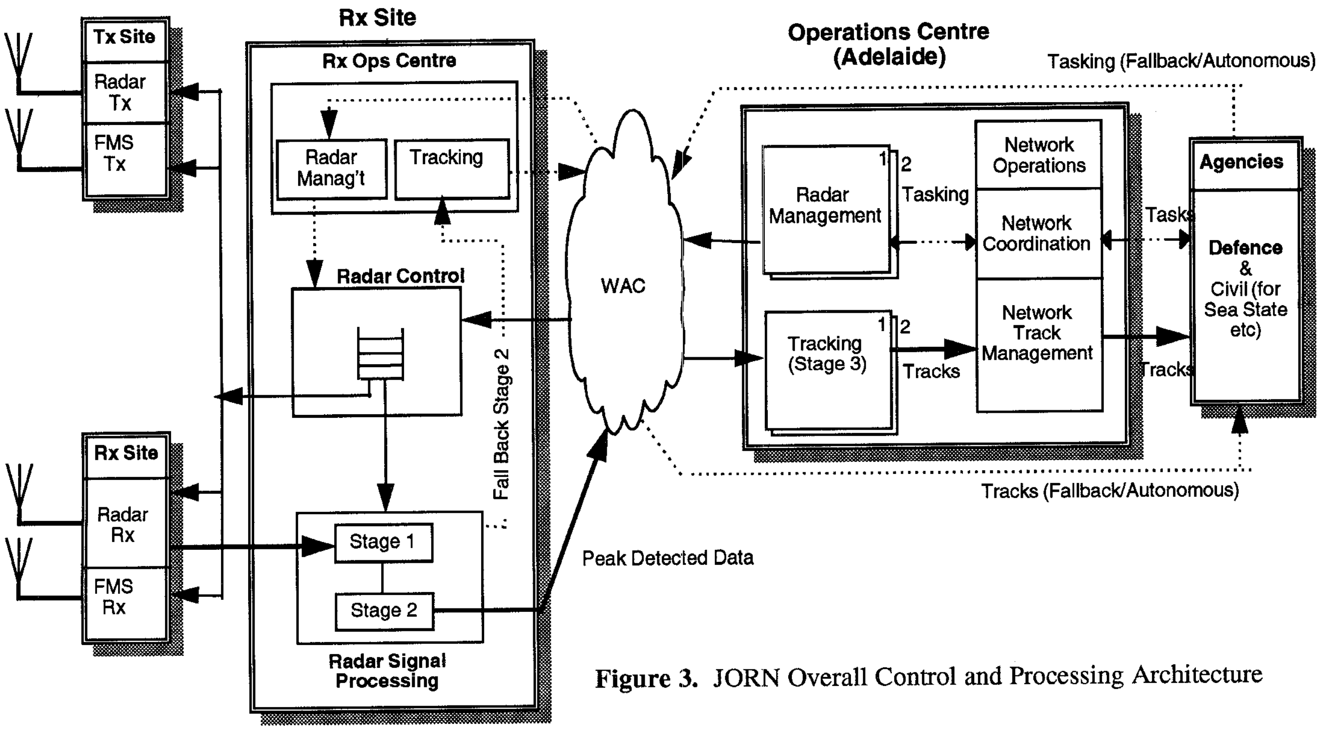


Figure 3. JORN Overall Control and Processing Architecture

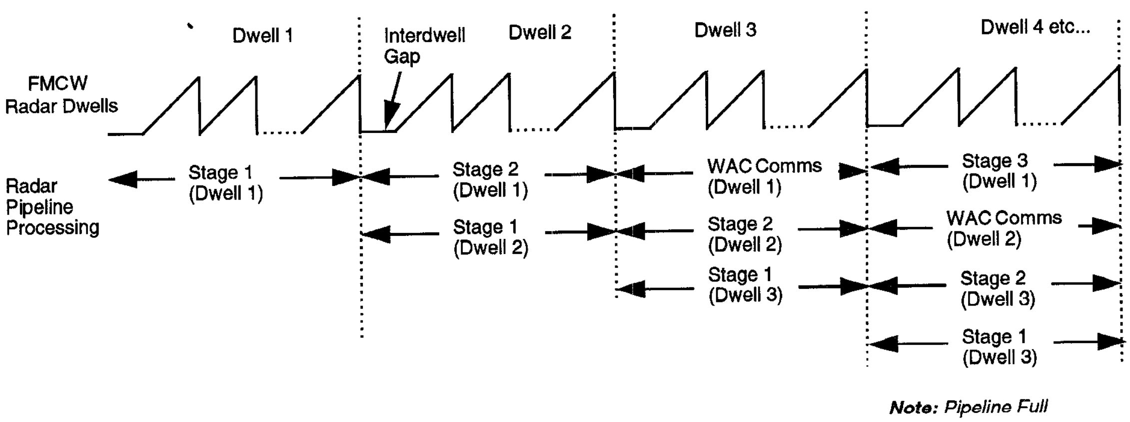


Figure 4. JORN Signal Processing Data Flow