Project Report
ATC-259

A Description of the Interfaces between the Weather Systems Processor (WSP) and the Airport Surveillance Radar (ASR-9)

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16 June 1997

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16. Abstract

The Weather Systems Processor (WSP) is an enhancement for the Federal Aviation Administration's (FAA) current generation Airport Surveillance Radars (ASR-9) that provides fully automated detection of microburst and gust front wind shear phenomena, estimates of storm cell movement and extrapolated future position, and 10- and 20-minute predictions of the future position of gust fronts. The WSP also generates six-level weather reflectivity free of anomalous propagation induced ground clutter breakthrough. Alphanumeric and graphical displays provide WSP-generated weather information to air traffic controllers and their supervisors.

This report describes the hardware, interfaces, timing and digital signal extraction from the ASR-9 necessary to support the WSP. The digital interface circuitry between the WSP and the ASR-9, the control functions associated with the WSP, and strategies for performing system test functions are described.

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1.0 INTRODUCTION

The Weather Systems Processor (WSP) is an enhancement for the Federal Aviation Administration's (FAA) current generation Airport Surveillance Radars (ASR-9). It provides Doppler estimates of low-altitude winds that are used to automatically alert controllers and pilots to the presence of microburst and gust front wind shear phenomena. The WSP also generates six-level weather reflectivity maps that are free of anomalous propagation (AP) induced ground clutter breakthrough. Scan-to-scan tracking of storm cells and gust fronts provides estimates of their velocity, as well as 10- and 20-minute predictions of the future position of gust fronts. The output of the WSP is presented on a graphical situation display (SD) for Terminal Radar Approach Control (TRACON) and air traffic control tower (ATCT) supervisors. Tower local controllers are provided wind shear alert messages on alphanumeric, or "ribbon" displays, for relay to pilots verbatim. These displays, shown in Figure 1, are similar to those used to depict the output of the Terminal Doppler Weather Radar (TDWR). Thus, the WSP provides comparable tactical information on microburst activity and strategic information for managing airspace and runways at medium-density airports.

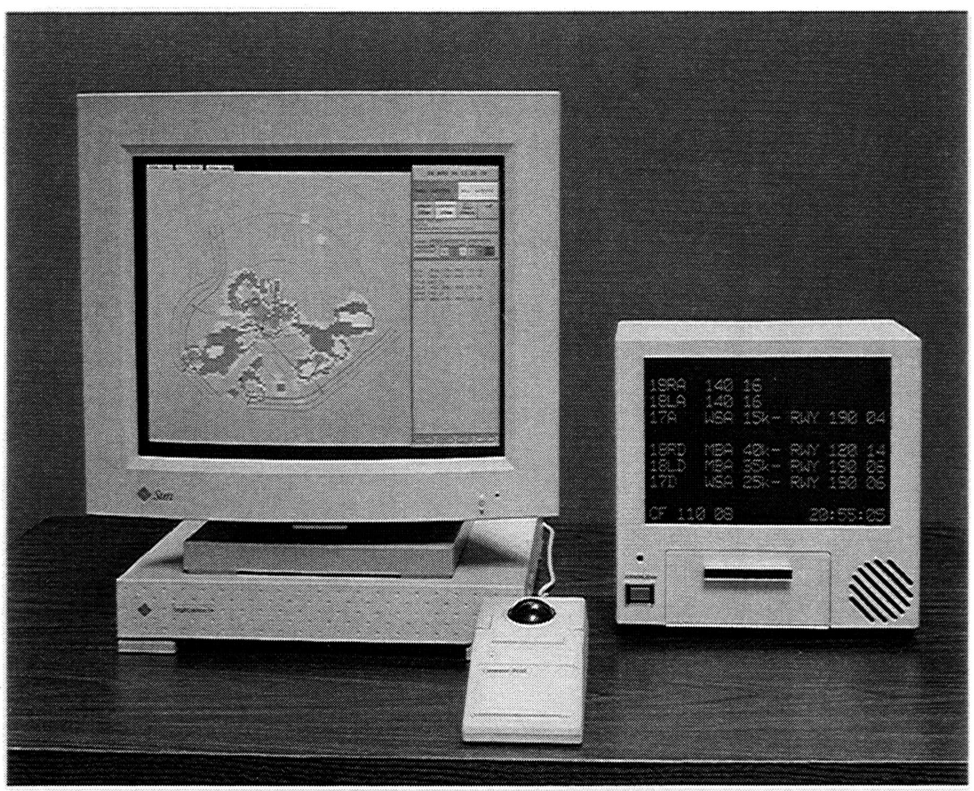

Figure 1. Supervisor's graphical situation display and local controller's ribbon display.

This report describes the hardware, interfaces, timing and digital signal extraction from the ASR-9 necessary to support the WSP. Section 2 provides a description of the ASR-9 system, with emphasis on aspects that are pertinent to the integration of the WSP. Section 3, an overview of the WSP architecture, emphasizes that the "outboard" subsystems of the WSP–its data processor, user displays and remote monitoring system–must be carefully tied into the ASR-9 through a suitably designed "front-end." The core of this report, Section 4, describes this front-end, or "Radar Data Acquisition" unit in detail. We summarize in Section 5.

2.0 PERTINENT ASR-9 FEATURES

This section describes the architecture of the ASR-9 with emphasis on features pertinent to integration of the WSP. The WSP functions, while often analogous to those of the ASR-9, will be largely freestanding to facilitate integration, testing, and use with other coherent, high-powered radars with a suitable two-beam antenna pattern and a dual-polarization feed.

2.1 ASR-9 Overview

The ASR-9, the latest generation Airport Surveillance Radar, was procured through a contract by the FAA with Westinghouse Electric Corporation (now Northrop Grumman Electronic Systems Division). Like earlier ASRs, its parameters are optimized for the detection and tracking of aircraft throughout a terminal airspace volume extending from the surface to 24,000 feet above ground level (AGL) and out to as far as 60 nmi. The transmitter operates in the 2.7 to 2.9 GHz band with over one million watts of peak power, a 1.2 μsec pulse, and better than 50 dB instability residue. The doubly-curved reflector antenna employs two feed horns (figure 2) which yield dual, overlapped elevation fan beams. The ASR-9 target channel and existing weather channel process signals from the high beam at shorter ranges (nominally 15 nmi and less) in order to reduce ground clutter illumination. Range-azimuth gated (RAG) microwave switches then select the low beam input for longer range processing.

The antenna is scanned in azimuth with a nominal revolution period of 4.8 seconds. The ASR-9 transmits a block-staggered pulse repetition frequency (PRF) waveform in order to mitigate aircraft blind speeds. During the interval in which the antenna scans through one azimuth beamwidth, ten pulses are transmitted at a "high-PRF", followed by eight pulses at a "low PRF"; the PRF ratio of these two pulse blocks is 7:9. Wind loading may cause the antenna rotation rate to vary by up to 10 percent. "Fill" pulses at the low PRF may be inserted at the end of the two pulse blocks (a so-called CPI-pair) in order to register the start of the next CPI-pair to absolute azimuth.

The radar can transmit either linearly (vertical) or circularly (right hand) polarized microwave energy. During clear conditions, the system will normally be in linear polarization (LP) mode. During rainy conditions, the radar can be placed in circular polarization (CP) mode in order to increase the signal to precipitation clutter ratio. This can be accomplished manually through a switch setting on the ASR-9 control box, or automatically through a selection criterion within the ASR-9 system. This criterion is based on the percentage coverage (over the entire radar field of view) of precipitation echoes exceeding a "light rain" threshold.

A dedicated signal reception and processing channel measures and contours precipitation reflectivity for display on controllers' radar scopes (Data Entry and Display System or DEDS and Bright Radar Indicator Tower Equipment or BRITE). This "weather channel" uses high-pass Doppler filters to suppress ground clutter, thresholds the precipitation echoes to six calibrated intensity levels and performs spatial and scan-to-scan smoothing. During LP operation, the weather channel input is from the target channel analog-digital (A/D) converters. When the radar is in CP mode, separate microwave paths and a dedicated super-heterodyne receiver are used to derive the appropriate (left hand circular) signal polarization from orthogonal ports on the antenna feed horns. A "two-level" weather function embedded within the ASR-9's target processor provides backup to this preferred six-level weather channel.

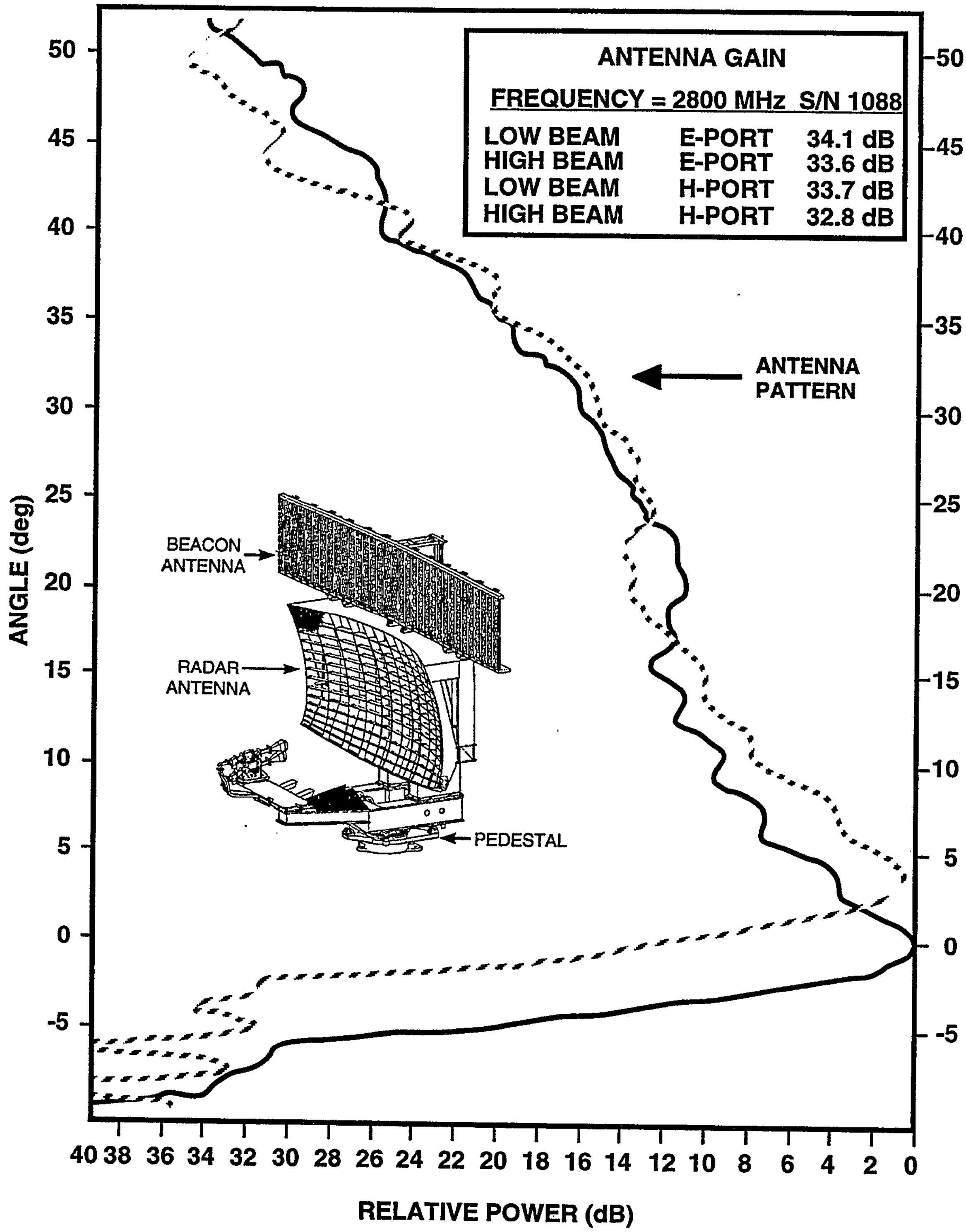

Figure 2. Antenna and high- and low-beam patterns. The ASR-9 antenna is comprised of a reflector, two feed horns, and a pedestal. The reflector carries an open array beacon antenna. The pattern shows the low beam at an elevation angle of 0°. This parameter is adjusted in accordance with the clutter environment at each site.

2.2 Antenna Feed Array

Figure 3 is a detail of the ASR-9 feed horn assembly. Shown are the high and low beam feeds, associated polarizing sections and the input/output ports that are connected via waveguide or coaxial paths to the transmitter and receiver sub-systems within the radar shelter. As noted, circular polarization may be employed to reduce the magnitude of precipitation echoes in the target channel. Precipitation echoes are delivered to the orthogonal or cross polarized port of the orthomode transducer while target channel signals are delivered to the co-polarized signal port. The polarizers in the high- and low-beam antenna feed horns employ electromechanically driven phase shifting units and 45° rectangular-to-square waveguide transitions.

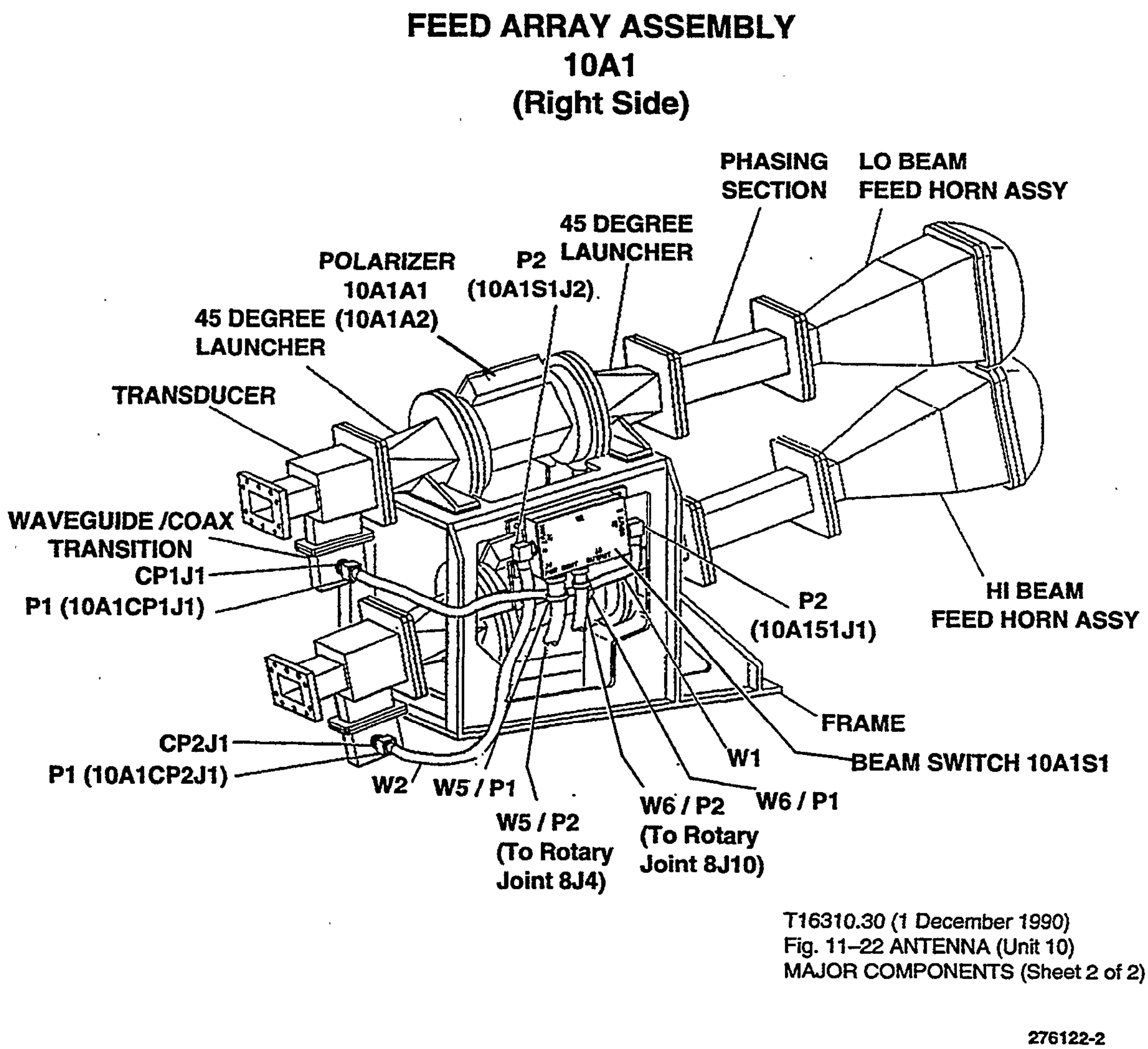

Figure 3. ASR-9 feed array assembly (10A1).

2.3 Radar Shelter Equipment

Figure 4 depicts the ASR-9's four-bay assembly consisting of redundant ("A" and "B" channel) transmitter and receiver/processor cabinets, the Remote Monitoring System (RMS) cabinet and the Six-Level Weather/Surveillance Communication Interface Processor (SCIP). The four-bay assembly is housed in an environmentally controlled radar shelter building located next to the antenna tower. This shelter is typically remote from the air traffic control tower and unmanned. Technician visits to the shelter for fault diagnosis and repair are minimized through use of the systems RMS functions.

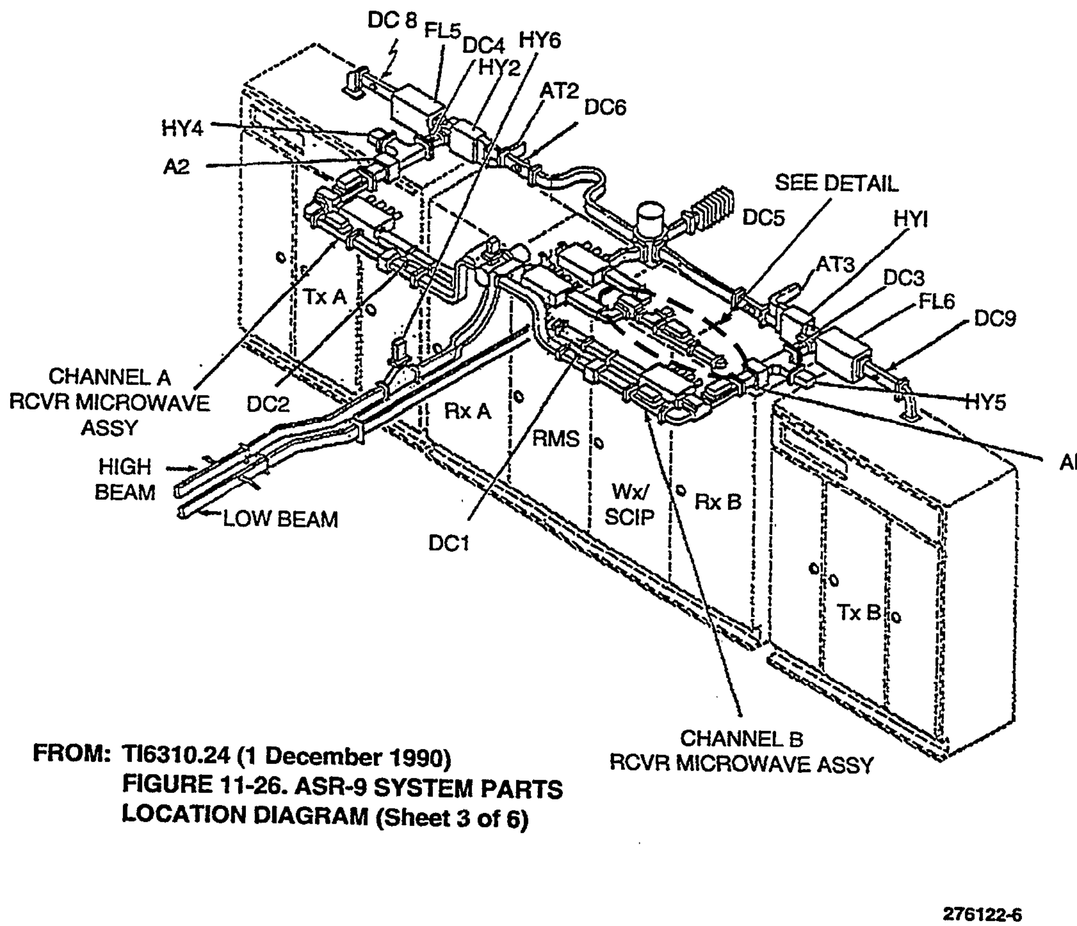

Figure 4. ASR-9 four-bay assembly, including the overhead array of microwave components for both channels.

Figure 5 is a detail of the waveguide components of the ASR-9 Six Level Weather Channel receiver. Physically, these are located in the radar shelter, above the four-bay assembly. As described in Section 4, these components are re-used in the installation of the WSP.

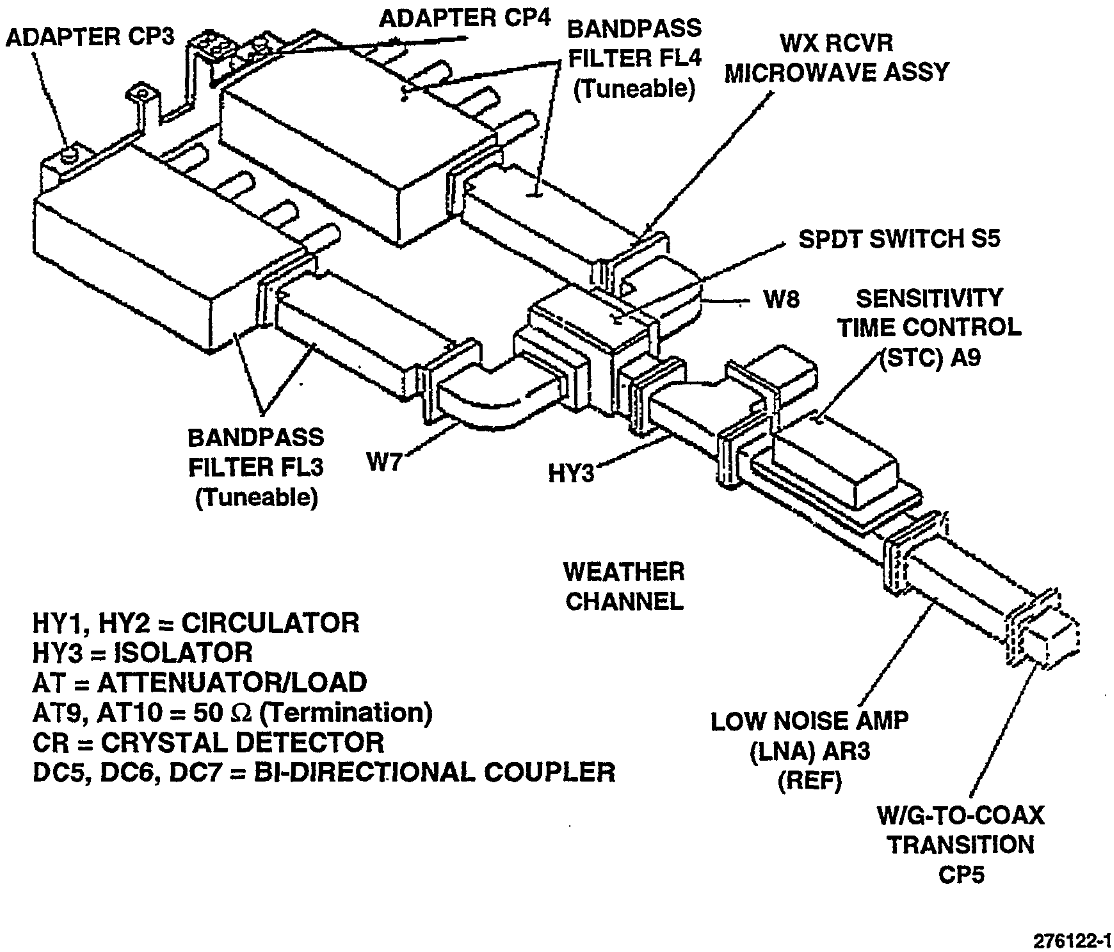

Figure 5. ASR-9 Six Level Weather Channel waveguide components, shown in their installed positions.

2.4 Six-Level Weather Processor

The ASR-9 employs a common architecture, control, and data flow for all signal processing functions in implementing its two target channels and six-level weather channel. Commencing with the components on the antenna and carrying through the target or six-level weather data output, the timing and signal processing, the gross block diagrams of the two target channels, and the six-level weather channel have a similar topology. All functions are implemented essentially independently in each channel as shown in Figure 6. The synchronizer, monitoring and control, RF-IF receiver components, A/D sampling (interrogate) pulses, batch timing, and calibration functions employed by the six-level weather receiver is nearly identical in form to the corresponding components in the ASR-9 target channels. In addition, the Weather Receiver/SCIP function incorporates communications for target (surveillance) data, beacon (ATCBI) triggers, and functional elements for formatting signals to feed a local maintenance display processor.

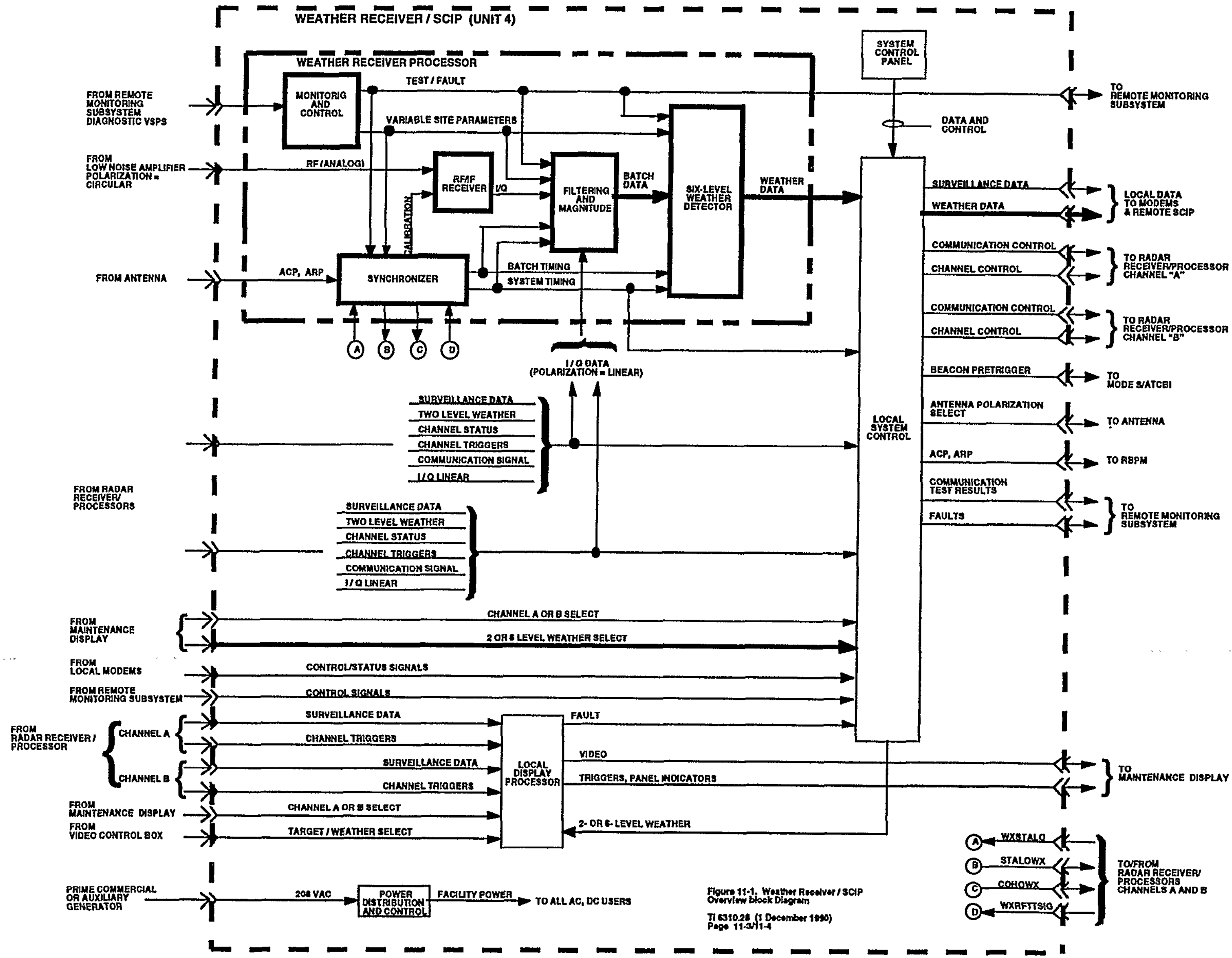

Figure 6. ASR-9 weather receiver/SCIP.

The ASR-9 Weather channel has a RF-IF receiver that includes a low-noise front end, a stable local oscillator, and mixer. A filtering and magnitude function is implemented in the six-level weather channel to handle the batches of A/D data comprised of samples from 18 pulses generated during the transit of each beam width. A six-level weather detector thresholds the processed batch data and performs spatial and temporal smoothing. The resulting data are passed to the message interface processor function of the system control for transmittal to modems and the ASR-9 Remote SCIP. A local display processor function feeds six-level weather triggers and video to a maintenance display.

3.0 WEATHER SYSTEMS PROCESSOR OVERVIEW

The WSP is comprised of four major functional elements: the Radar Data Acquisition (RDA) unit, the Radar Data Processor (RDP), the Display Function (DF) and a Remote Monitoring System (RMS) (See Figure 7). The RDA acquires radio frequency (RF), timing and reference signals from the ASR-9, as well as accomplishing various control functions described below. The RDP consists of commercial off-the-shelf (COTS) processors, housed in a VME chassis. The RDP performs processing to suppress interference such as ground clutter and out-of-trip weather, to estimate precipitation reflectivity, Doppler velocity and spectrum width, and to generate meteorological products. As shown, the RDP also hosts the drivers and media for data archiving. The DF is comprised of the SDs and Ribbon Display Terminals (RDTs) described previously; these are moderately priced, COTS computer systems. The RMS monitors critical system performance data to identify and isolate failures, and provides the operator interface to the WSP.

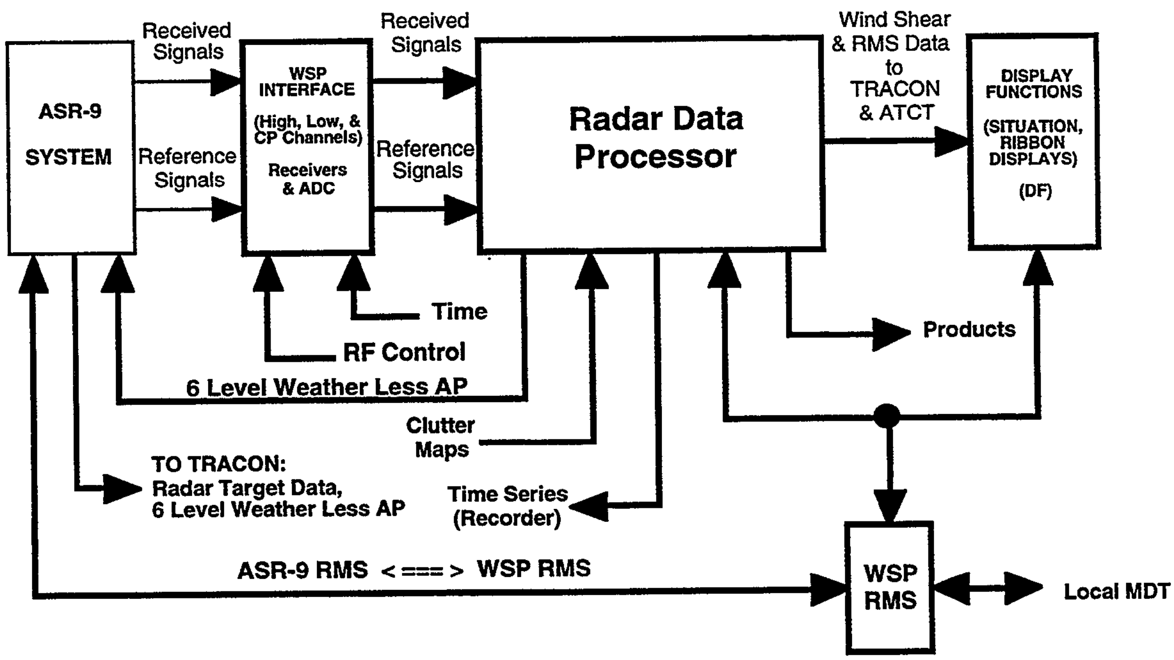

Figure 7. ASR-9 and WSP High Level Block Diagram.

3.1 Radar Data Acquisition

Broadly, the RDA accomplishes four functions: (1) microwave signal acquisition; (2) timing, reference and digital signal acquisition; (3) control; and (4) RDP input synchronization.

Radio frequency (RF) signals from the linearly polarized (LP) and circularly polarized (CP) high- and low-beam ports are connected to a microwave switch matrix that makes the appropriate beam selection, choosing between the high- and low-beam signal on alternate scans of the antenna. Signals from the ASR-9 are monitored to determine which channel (A or B) and which polarization are active. The RDA includes a dedicated, high dynamic range receive chain that provides the primary input to the WSP's Doppler processing algorithms. Intermediate frequency (IF) test signals generated by the ASR-9 circuits and coupled directly into the WSP are available for use during the 48-range gate calibration interval which is programmed during the eight-pulse coherent processing interval block. The weather test signal is used for off-line calibration. It is controlled in range, azimuth, Doppler spectral width, and amplitude by the ASR-9 RMS.

Timing signals (e.g., COHO), antenna (azimuth) and reference change pulses used by the WSP are transmitted across the interface. In addition, digitized quadrature samples are extracted from the ASR-9's existing A/D converters for use in extending storm reflectivity and motion processing to the radar's full coverage range, and in correcting for signal depolarization effects as described later in this report.

The WSP control function determines the "start of scan," and controls the RF switch matrix as a function of radar polarization state (LP or CP), active channel selection, antenna scan count and target channel Range-Azimuth Gating (RAG). (See Figure 8).

The primary output of the RDA is digitized quadrature samples from the dedicated WSP receive chain, multiplexed with synchronous samples from the target channel A/D converters. These are formatted in "pulse records," each consisting of all (960) range gate quadrature samples for each transmitted pulse repetition interval and accompanied by ancillary data necessary for the RDP functions. The pulse records are clocked to the RDP via a 32-bit wide parallel interface at a rate consistent with the ASR-9 range sampling interval of 1.3 MHz.

Details of these functions are described in Section 4.

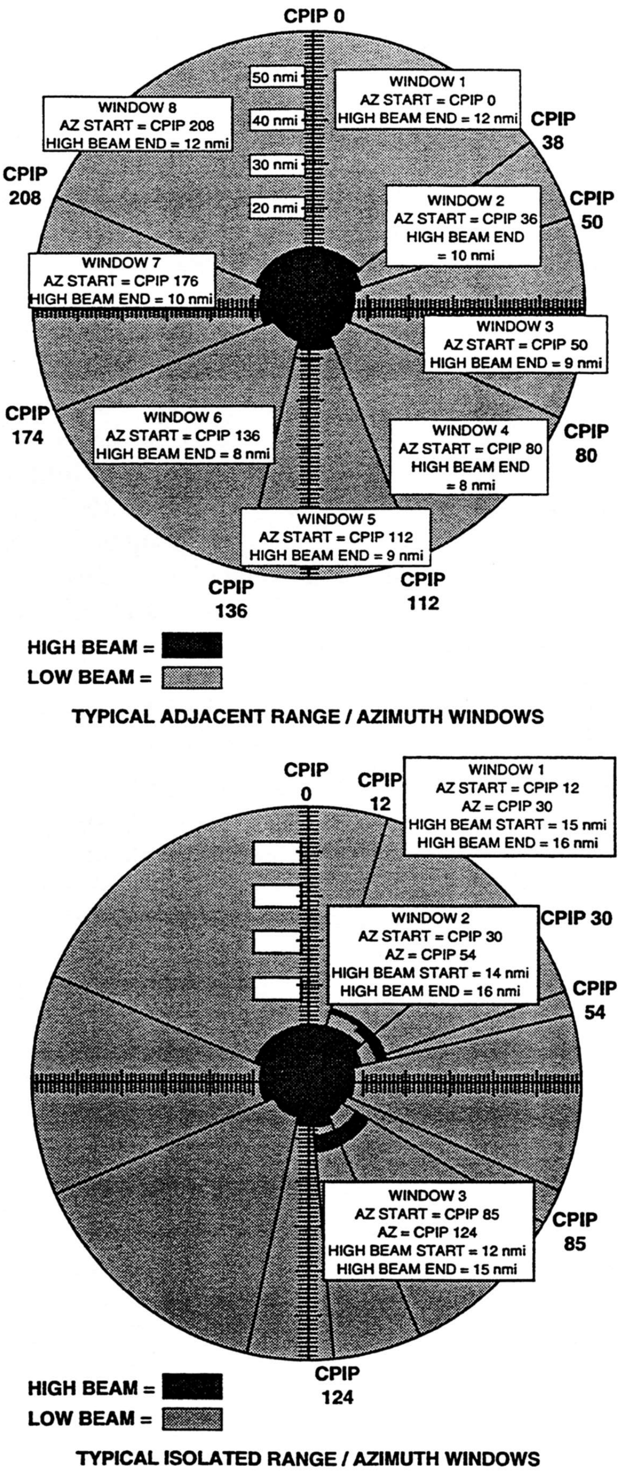

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Figure 8. Fourteen range azimuth windows exist. Eight of these windows begin at zero range and extend to a programmable range; the maximum range is 60 nautical miles. These eight windows can be programmed to end at different ranges or end all at the same range. All eight windows comprise 45-degree azimuth sectors which abut. The window segments chosen define the areas of low-beam utilization and in the areas of range azimuth inside the defined windows where the high beam is used. Six other windows exist which have both programmable start and stop ranges and azimuths. Two of these windows, 13 and 14, are reserved for use by combined threshold functions.

3.2 Radar Data Processor

The RDP is comprised of commercial off-the-shelf single-board computers, interconnected through a VME-standard backplane. It accomplishes the entire suite of data processing operations required to convert input radar quadrature samples to images of precipitation reflectivity, Doppler velocity and spectrum width ("base data"), and to extract user-oriented meteorological products from these.

Figure 9 shows the RDP configuration currently deployed in the Lincoln Laboratory WSP prototype. All processing cards are housed in a single, 19" VME-chassis. The RDP's input is from a single custom-built VME-data interface (VDI) card (part of the RDA) that formats quadrature samples as described above and transfers them onto a high-speed bus connecting a set of signal processing cards. These accomplish ground clutter suppression, range/Doppler ambiguity detection and generate a suite of base data images for input to the meteorological detection algorithms. Each signal processing card handles a subset of the range gates processed by the WSP. Reference [1] describes the WSP base data generation algorithms and their relationship to the control functions of the RDA.

Meteorological product generation is accomplished by single-board UNIX workstation equivalent computers. Algorithms on these boards perform (1) microburst detection, (2) gust front detection, tracking and future position extrapolation and (3) storm movement estimation/future position extrapolation. A Global Positioning System (GPS) clock assigns time to base data and meteorological products. Additional boards control data archiving (via small computer systems interface (SCSI) disks and 8 mm tape drives) and a local meteorological data display and monitoring console. The software within the RDP is single language (C/C++), POSIX-compliant and includes a variety of unit-test, process monitoring and debugging utilities.

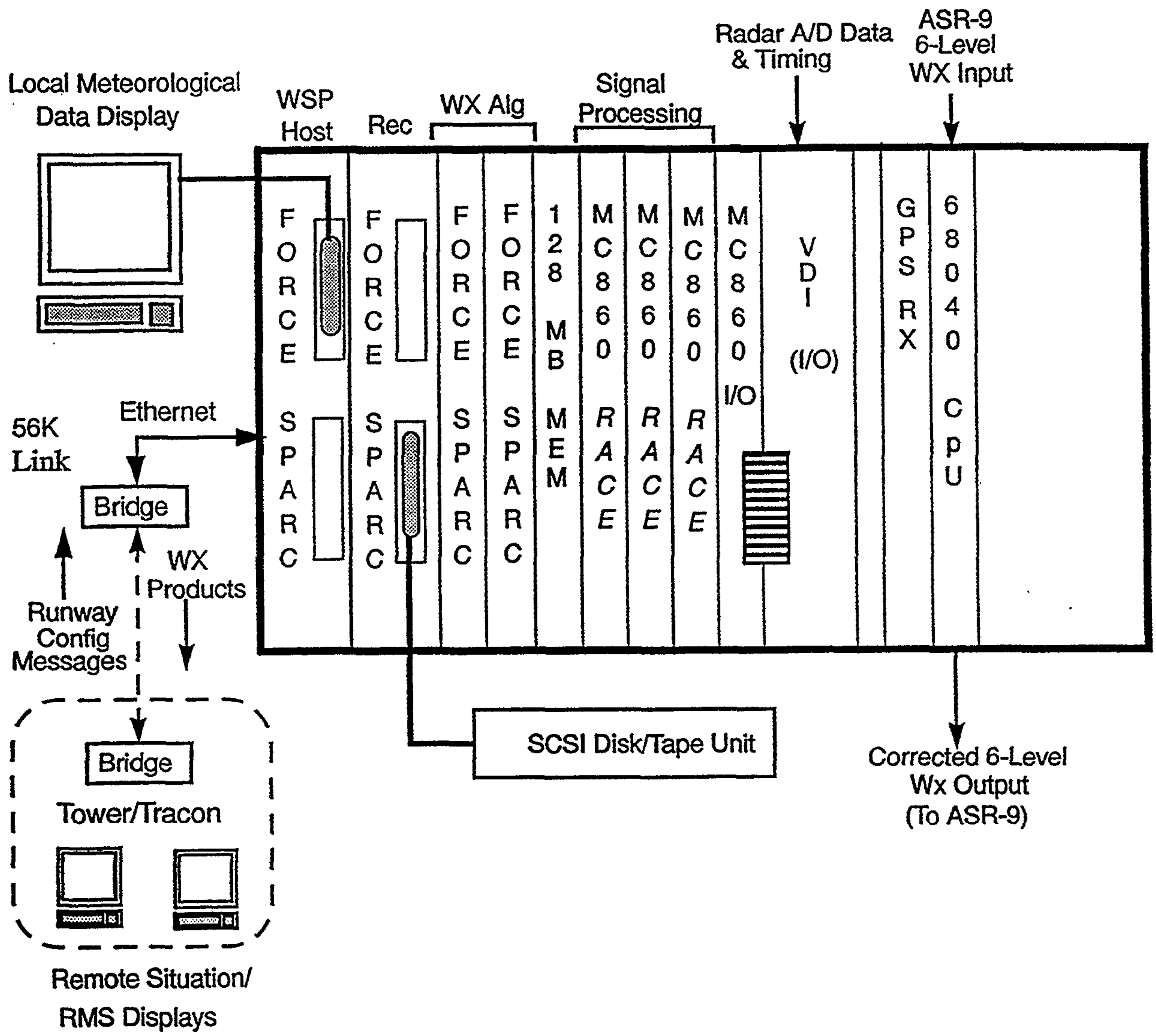


Figure 9. Lincoln Laboratory prototype WSP Radar Data Processor (RDP) configuration.

3.3 Display Function

Meteorological products from the algorithms within the RDP are transmitted asynchronously to the DF via a TCP-IP Ethernet protocol. There, they are decoded, used to generate runway specific alphanumeric alerts where appropriate and displayed. The DFs accept numerous user configuration commands (e.g., maximum range, active runway configurations, displayed product selections, geographic reference map selections). Both "handshaking" and "broadcast" protocols are available for communications between the RDP and each DF. The former is appropriate for critical users such Air Traffic controllers who require extremely high reliability and immediate fault detection. The broadcast protocol is more efficient for supporting remote users with less critical responsibilities relative to the use of WSP products (for example, airline operations personnel.)

Each DF unit consists of a Situation Display (a UNIX workstation or PC running a UNIX environment) and one or more Ribbon Displays. The latter may be dedicated alphanumeric monitors, or in some cases may be implemented as separate virtual windows on the SD. The DF software is again C/C++ and employs many of the graphical interface tools and drivers used in the RDP monitoring processes.

3.4 Remote Monitoring System

The WSP RMS function is comprised of:

1. Test points throughout the WSP system for collection of essential performance monitoring and fault detection data (these may include built-in diagnostics within the COTS components of the WSP);

2. An interface to the existing ASR-9 RMS to extract performance parameters monitored by that system that are also critical to WSP (for example, transmitter status);

3. Software for processing user commands, collecting and analyzing subsystem performance monitoring data and fault indication, and for generating systems alerts and alarms. The body of this software will run on a single-board computer (68040 CPU) within the WSP VME-chassis;

4. A local Maintenance Data Terminal, the WSP technicians' primary interface to the WSP;

5. An interface to the FAA National Airspace System (NAS) Infrastructure Monitoring System (NIMS), a central system monitoring facility under development by FAA.

Details of the RMS performance monitoring and user interface functions are to be developed by the WSP production contractor and approved by the FAA. Where appropriate, aspects of the WSP RMS–as they apply to RDA functions–are discussed in "concept" form in subsequent sections of this report.

4.0 THE WSP RADAR DATA ACQUISITION FUNCTION

The RDA provides the system-specific interface between an existing unit (the ASR-9) and the often markedly different signal processing operations performed by the WSP. In combination with the necessity of leaving existing ASR-9 search radar performance unaltered, the following WSP processing requirements dictate the design of the RDA.

1. Linearly or circularly polarized signals are processed from the high and low beams on alternate scans using the microwave components of the ASR-9 six-level weather channel in combination with a new, high-dynamic range IF receiver. The microwave circuits and IF receiver are configured to acquire and process the weather signals from the two antenna beams on alternate antenna scans.

2. The WSP operates alternately from either a high beam or a low beam connection. The high-beam mode is a receive only (passive) mode which is utilized at short range to reduce signals arising from ground clutter. The low beam is used for all transmission, and for target detection it operates at pre-designated ranges beyond local clutter. Control signals which select the required mode originate in STU A (A4A120). In a particular beam mode, various windows are specified to define the range and azimuth using variable site parameters (VSPs) (See Figure 8).

3. A secondary input to the WSP Radar Data Processor is provided through the active target channel receive chain and digitization circuits. These extend WSP coverage to full range (LP mode) or allow for signal depolarization correction to be implemented (CP mode).

4. To accommodate the large dynamic range of weather signals and clutter, an instantaneous automatic gain control (IAGC) is used by the WSP IF receiver. Signals used by the WSP for critical wind shear detection functions near the airport (i.e., at short range) must be detected through this receiver as opposed to the existing ASR-9 target channel receive chains.

5. A 27-pulse extended coherent processing interval (ECPI) is used by the WSP to suppress ground clutter and estimate base data fields.

6. The WSP signal processing function accounts for the presence of fill pulses when the ASR-9 antenna rotation slows and for signal loss due to depolarization of circularly polarized waves.

7. A stand-alone synchronizer is used to ensure that A/D interrogation and other WSP functions do not impact the operation of the target channel and to accommodate special timing functions for the batch processing.

8. To account for fill pulses properly in forming a 27-pulse coherent processing interval, a ring buffer is used to recover eight samples from the prior coherent processing interval pair (CPIP). (When the antenna speed slows because of wind loading, fill pulses occur until the appropriate antenna position is reached for the

next coherent processing interval pair to begin. This operation registers the ASR-9 geocontrol and censoring maps with the terrain). To facilitate identification of data, each pulse repetition interval is marked with the bearing, time of day, antenna beam position, and A/B channel selection and polarization. When archived, date and time of day are recorded in the header.

9. Circular polarization signal intensity is corrected by appropriate combination of the co- and cross-polarized signals. As the microwave signals transit rain, they experience a phase shift that impacts the 90-degree or quadrature relationship established by the circular polarizer. This depolarizing effect reduces the signal intensity output of the orthogonal (weather) port of the feed horn. To compensate for the loss in signal intensity in the weather port, the signal from the co-polarized (target channel) port is detected and combined with that of the orthogonal port to obtain an accurate estimate of storm intensity.

4.1 Microwave Signal Acquisition

All of the WSP product generation algorithms utilize base data imagery constructed from both high and low receive beam signals acquired nearly simultaneously (i.e., within a time interval small relative to that required for significant change in the precipitation or wind field). The two signal channels are either processed in parallel (for example to form "high" and "low" beam reflectivity images) or in combination. For example, detection of microbursts requires synthesis of a "dual-beam" velocity image that reflects the near surface component of the wind field in thunderstorm outflows. Discrimination between gust front "thin line echoes" and mimicking cloud features is aided by inter-comparison of reflectivity and Doppler velocity imagery acquired from both beams. The reflectivity estimates which serve as the basis for controllers' six-level weather maps, and as the input to the storm motion algorithm, are constructed as a range-dependent linear combination of power estimates derived from the two beams.

4.1.1 Target Channel Waveguide Modifications (Linear Polarization Mode)

When operating in linearly polarized mode, both the high- and low-beam signals are derived from the target channel (vertically or co- polarized) ports of the antenna. These ports in the unmodified ASR-9 are connected by waveguide transmission circuits to the solid-state, high-speed, RAG high-low beam switch mounted above the equipment rack in the radar shelter. Selector switches in each channel make connection from the waveguide, connected to the high and low beam horns on the antenna, to the active (A or B) channel high-low beam switch.

4.1.1.1 Low Beam Interface

At short range, where Doppler processing and wind shear detection is operationally critical, low beam signals must be processed through the dedicated, high-dynamic range WSP receive chain. This is accomplished by shunting the unused low-beam signal to the WSP receiver over the short range interval (nominally 0 to 15 nmi) where the target channel processes high beam signals. At greater ranges, low beam signals for the WSP are acquired from the active target channel A/D converter.

To accommodate the WSP with minimal impact on the performance of the low-beam signals used by the target channel, the ASR-9 waveguide is rearranged (See figures 10 and 11). A second high-speed, single-pole, double-throw (SPDT) waveguide switch is installed in each channel (SW101, SW102) to extract the low-beam signal for processing in the RDA. The added switch is slaved to the existing RAG beam switch (S2, S3) so as to direct the low-beam signal to the RDA receiver when the high-beam horn is connected to the target channel receiver. The low-beam signal is connected to the target channel receiver under ASR-9 RAG control beyond the nominal 15 nmi range.

The insertion loss associated with these added waveguide switches increases the ASR-9 target channel's low-beam receiver minimum detectable signal (MDS) by approximately 0.5 dB. This will decrease the nominal detection range for a 1 square meter aircraft on the nose of the beam by roughly 2 nmi. Since the ASR-9 system exceeds its detection envelope requirement by more than this margin, the resulting decrease in performance is not expected to have an operational impact on its aircraft surveillance function.

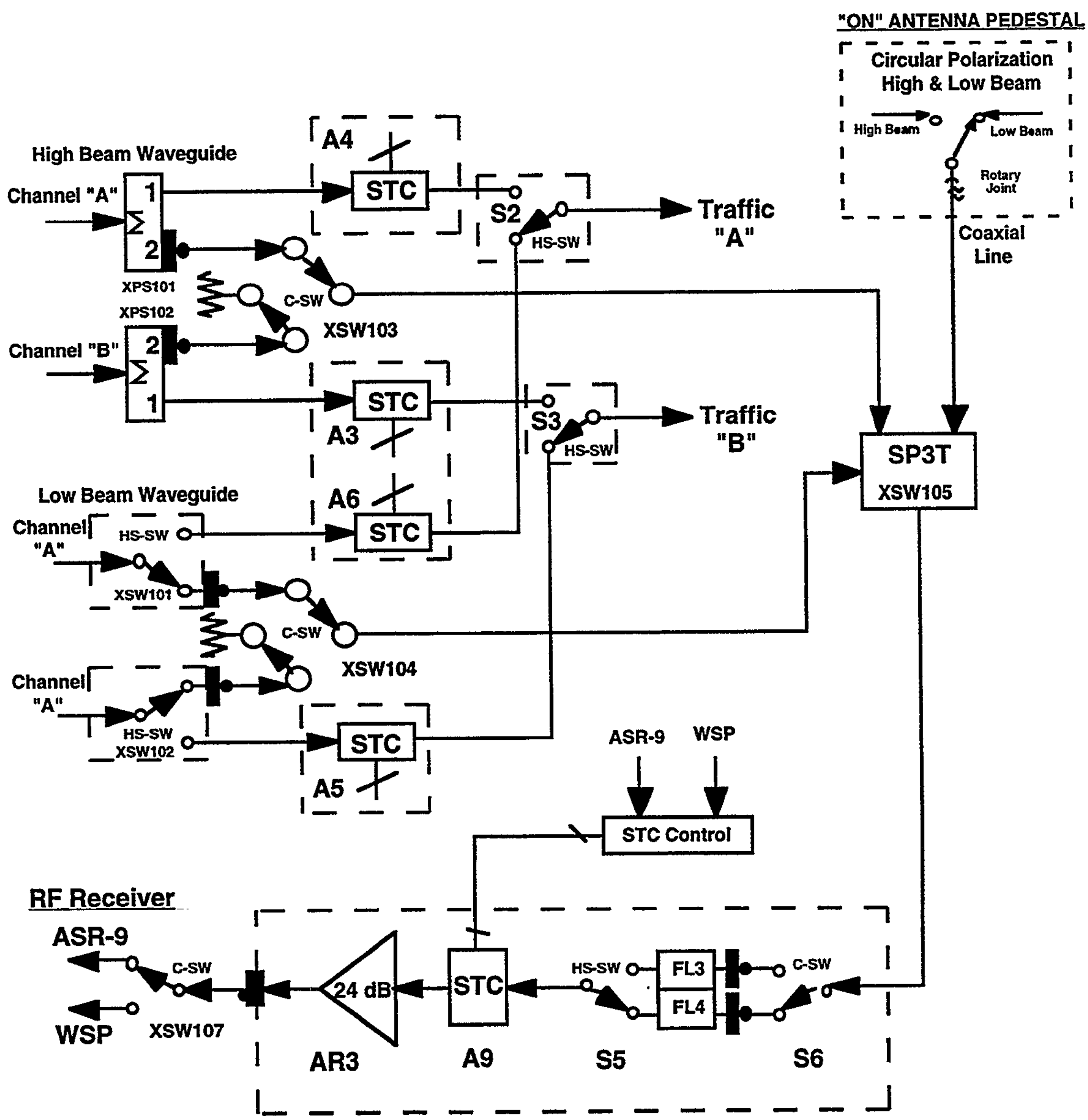
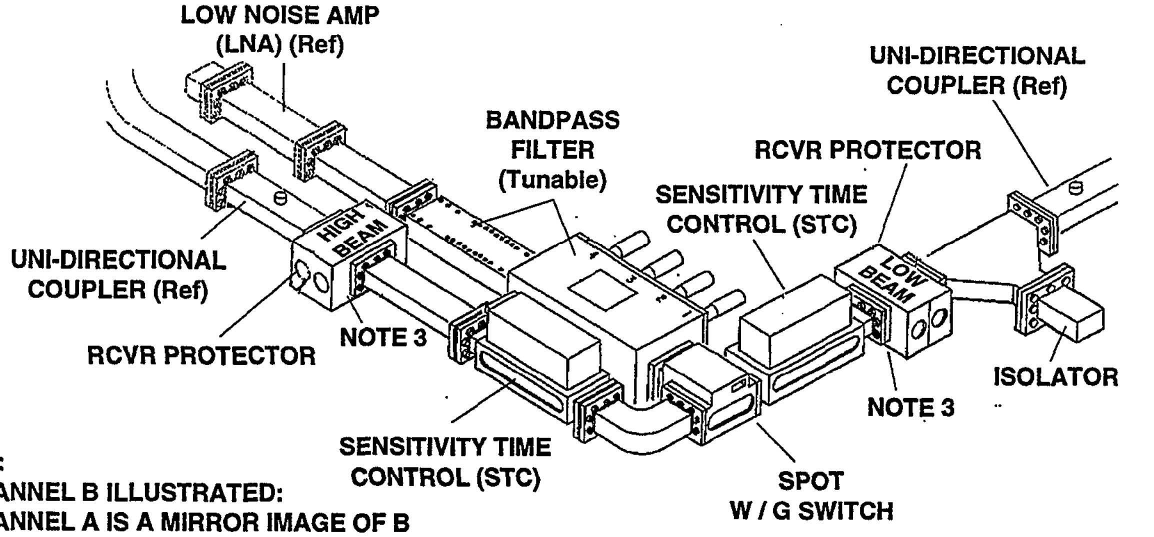


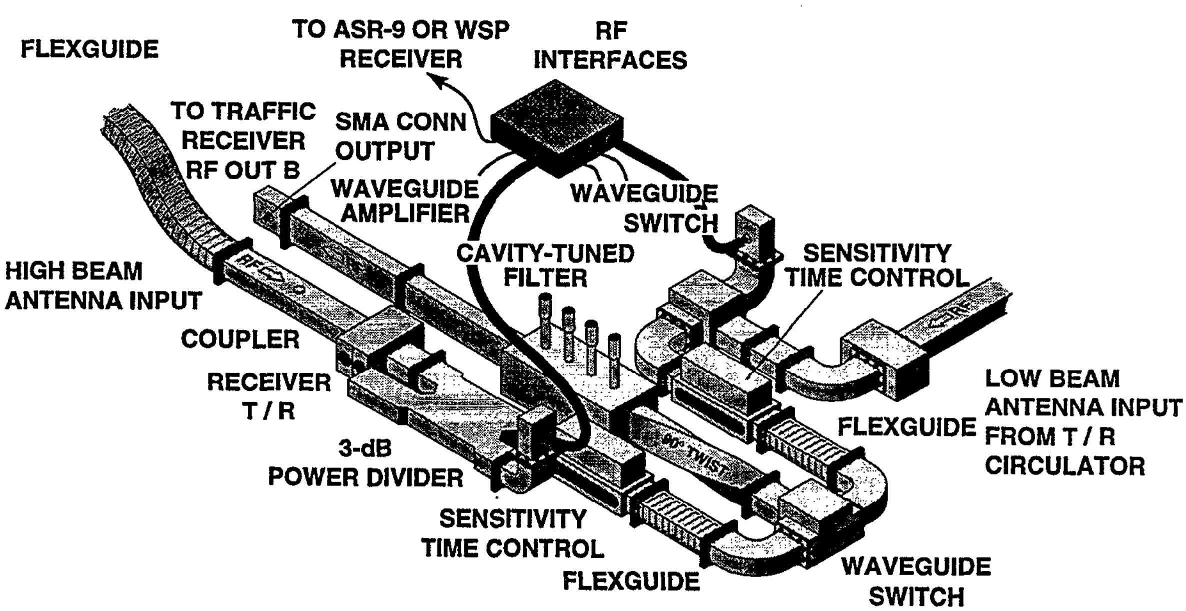
Figure 10. Simplified Waveguide Assembly Line Drawing.

ASR-9 WAVEGUIDES



NOTE:
1. CHANNEL B ILLUSTRATED:
   CHANNEL A IS A MIRROR IMAGE OF B
2. WSP HARDWARE
   INSERTION POINTS

ORIGINAL CONFIGURATION



WSP MODIFIED WAVEGUIDE CONFIGURATION

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Figure 11. Waveguide assembly. Original configuration and modified configuration.

4.1.1.2 High Beam Interface

In contrast to the low beam mode of acquisition, the target channel's use of high beam signals at short range precludes their exclusive use by WSP. The target channel's receive chain design–specifically application of up to 60 dB Sensitivity Time Control (STC) attenuation, and limited (63 dB) instantaneous dynamic range–preclude use of the target channel A/D converter output for WSP. In linear polarization mode, the only feasible method for WSP acquisition of high beam microwave signals is through insertion of a power divider in the target channel receive path. Compensation for the insertion loss to the target channel is accomplished by corresponding adjustment to the target channel STC attenuator, normally feasible over the short range interval where high beam signals are employed by the target processor.

Three dB directional couplers (XPS101, XPS102) are installed in the high-beam waveguides feeding, respectively, the A and B target channel circuits. The second output of the on-line channel high beam 3 dB coupler is selected by a SPDT XSW103 electromechanical switch and is sent to an input of a single-pole, triple-throw (SP3T XSW105) switch whose output feeds the receiving components used by the WSP.

As noted, the received signal energy loss to the target channel is compensated for by reducing the STC attenuation applied downstream of the power divider. This is obviously feasible only when the baseline STC exceeds 3 dB. Since the ASR-9's nominal high-beam STC curve will drop below 3 dB several miles before the nominal switch-over to low beam target channel processing, the WSP's power divider reduces upper elevation angle coverage over the last several miles prior to this switch-over. In order to preclude a surveillance "hole" at high altitude, the RAG high-low beam switch range may be moved in several miles. Analysis by engineers at Northrop Grumman, the manufacturer of the ASR-9, have indicated that specified surveillance coverage can be maintained with appropriate adjustments to the system's Variable Site Parameters (VSPs).

It is possible that clutter resulting from distant mountains necessitates switching back to the high beam at ranges well beyond the nominal 15 nmi transition point. Since STC will normally not be appropriate at such ranges, a potential loss of aircraft detection may occur in this region if the target cross-section is less than 2 square meters.

Note that the minimum detectable signal for the high beam receive path is also reduced 3 dB with this acquisition mode. This is unavoidable owing to the constraints associated with avoiding significant impact to the ASR-9 target channel.

4.1.2 Weather Channel Microwave Path Modifications (Circular Polarization Mode)

As noted, weather processing functions during CP transmission mode must utilize signals from the orthogonally polarized antenna ports. The ASR-9 system has only one path through the rotary joint for these signals and requires that high-low beam selection be accomplished at the antenna. A high-speed switch (10A1S1) mounted on the antenna selects the high or low beam and sends its output through a single coaxial run to the equipment shelter. The existing ASR-9 weather channel employs a RAG beam selection mode (nominal high to low beam switch-over occurs at 32 nmi) and processes only one beam in any range gate.

When the WSP is on-line, its RDA assumes control of this beam switch to allow for near-simultaneous (alternate scan) acquisition of signals from both beams in all range gates. The low beam signal is processed by the WSP for all range gates for one full antenna scan; the switch then toggles so that high beam signals are processed during the following scan. As shown in Figure 10, the WSP's SP3T (XSW-5) switch is connected to the coaxial microwave path to select the orthogonally polarized ports for input to the WSP RF/IF receive chain in CP mode.

It should be noted that the coaxial microwave paths employed by the ASR-9 for the orthogonally polarized signals exhibit significantly greater transmission loss than the waveguide runs used for the target channel inputs. Depending on the antenna tower height and radar shelter configuration, the loss through the coaxial runs may range from 3 to 7 dB. This will of course result in an associated increase in minimum detectable signal for the WSP.

In summary, the WSP interconnection to the ASR-9 microwave signals involves the following elements shown in figure 10:

- High-beam extraction via an added 3 dB power splitter (LP mode);
- Low-beam extraction via an added waveguide SPDT switch (LP mode);
- A or B channel selection; one for high beam, one for low beam (LP mode);
- High- and low-beam CP extraction via reconnecting and reprogramming the existing orthogonal port SPDT (10A1S1) switch to support alternating scan data collection (CP mode); and
- A single pole, triple throw (SP3T) switch to select the appropriate signal to the WSP receive chain.

4.1.3 WSP Receive Chain

Microwave components of the WSP receive chain–largely re-used from the existing ASR-9 weather channel–are diagrammed in Figure 10. Switches S5 and S6 route input signals to the appropriate pre-selector FL3 or FL4. These are band pass filters tuned to the "A" or "B" channel transmitter frequencies; in combination with other ASR-9 components these filters eliminate interference from out-of-band sources. In contrast to the ASR-9 target channel and existing weather channel, the PIN-diode STC attenuator is under programmable map control, and is used only in a limited number of range-azimuth sectors to prevent low noise amplifier (LNA) saturation. The LNA provides gain of approximately 24 dB; its dynamic range (nominally 95 dB) sets the limits within which the subsequent IF receiver and A/D converters operate. A stable local oscillator (STALO) is mixed with the LNA output to derive the intermediate frequency output at 31.1 MHz.

The microwave components of the receiver that are mounted above the radar cabinets are shown in Figure 5.

4.1.3.1 Intermediate Frequency (IF) Receiver

The ASR-9 target channels and six-level weather processor use quadrature video (I&Q) detectors and two 12-bit A/D converters. Servo circuits matches the amplitude and maintain the phase quadrature of the I and Q signals. The digitized output comprised of two 12-bit words is fed to the ASR-9 target channel or six-level weather processors. These well proven circuits could be used by the WSP with the addition of instantaneous automatic gain control (IAGC) at the IF stage in order to match the A/D converter dynamic range interval to that of the front end LNA. However, 14-bit or greater signal quantization is preferred, which will require additional circuit modification. Northrop Grumman engineers are also examining a direct digitization coherent detection receiver as described below.

4.1.3.1.1 Direct Digitization

Recent developments in direct digitization of IF signals make possible the elimination of the quadrature video circuits used in the ASR-9. To implement direct digitization, a reference derived from the ASR-9 coherent local oscillator (COHO) is used to mix the WSP IF signal down to 3.9 MHz with a 1.3 MHz bandwidth. This signal is sampled with an A/D converter operating at 5.2 MHz. The I&Q data are recovered from the digital samples. The scheme, referred to as "direct sampling quadrature detection," eliminates one A/D converter and the critical matching problems associated with quadrature video detectors. Note: The above description is conceptual; the implemented concept may differ.

4.1.3.1.2 Instantaneous Automatic Gain Control (IAGC)

An instantaneous automatic gain control (IAGC) is implemented on a pulse-to-pulse basis by storing 960 range samples of the amplitude of WSP signals received during one pulse repetition interval (PRI) and using them on a cell-by-cell basis to program the AGC attenuator and thereby maintain the receiver within its linear range. This technique is possible, for the weather echoes remain correlated for several pulse repetition intervals. A correction for the value of AGC attenuation must be made on a cell-by-cell basis on the data for the subsequent set of samples.

The IAGC function requires new circuits to control its attenuator and an appropriate storage register for the IAGC data must be added to store the 960 weather samples during a pulse repetition interval (PRI). A ping-pong memory arrangement is needed for the IAGC operation owing to the need to read the data from the previous sweeps for processing the current sweep. A conceptual block diagram is shown in Figure 12.

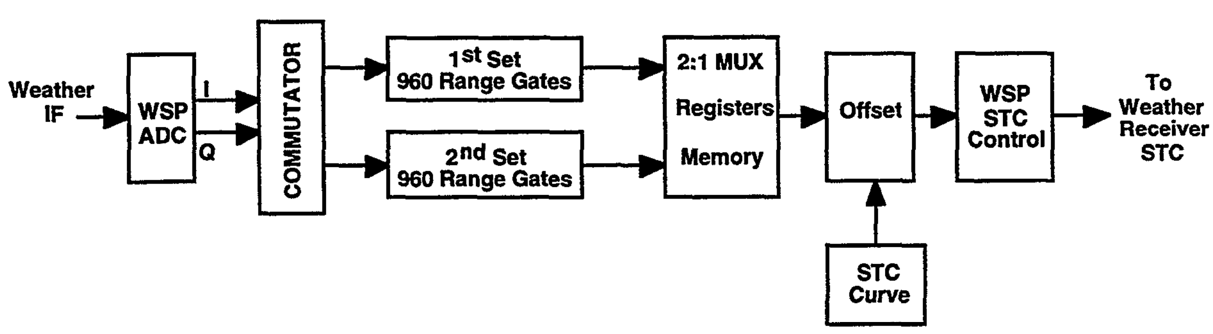


Figure 12. Conceptual design diagram for WSP IAGC circuit. The circuit implemented may differ in topology.

4.2 Timing, Reference and Digital Signal Acquisition

In order to control its microwave signal acquisition circuits, drive its dedicated IF receive chain and A/D converters, and perform its base data generation functions, the WSP requires non-intrusive access to a number of ASR-9 internal system signals. The settings of the beam switches used to select the appropriate ASR-9 antenna port output for the WSP receiver depend on the radar's active channel selection, polarization mode (LP or CP), RAG beam switch setting and a scan counter derived from the Azimuth Reference Pulse/Azimuth Change Pulse sequence. The WSP's dedicated IF receiver requires the active channel coherent oscillator signal for derivation of frequency sources necessary for down-conversion and A/D sample strobes. Signals defining the time of pulse transmission synchronize the WSP quadrature samples to those generated within the ASR-9 system. Finally, as noted ASR-9 target channel samples are necessary to provide long range, low beam data (in LP mode), or to correct for signal depolarization biases (in CP mode).

Table 1 defines the interfaces between the ASR-9 system and the WSP. For completeness, the table lists the interfaces for necessary microwave signal acquisition (treated in Section 4.1) and for feedback of WSP-generated six level weather into the ASR-9 system. Not all of the items will be used by the WSP, for the functions may be derived by the WSP or may not be required.

Table 1
ASR-9 to WSP Interconnections

ASR-9 Source			WSP
Functional Name	Signal Name	Part Name /Tie Point	Part Name /Tie Point
Break-out "A" high-beam target channel, for WSP	WSP "A" high beam	XPS101 Cha. A Power splitter	RF interface box: Cha. "A" high beam
Break-out "B" high-beam target channel, for WSP	WSP "B" high beam	XPS102 Cha. B Power splitter	RF interface box: Cha. "B" high beam
Break-out "A" low-beam target channel signals	WSP"A" low beam	XSW101 Cha. A Beam switch	RF interface box: Cha. "A" low beam
Break-out "B" low-beam target channel signals	WSP "B" low beam	XSW102 Cha. B Beam switch	RF interface box: Cha. "B" low beam
CP weather signals, from antenna	CP Channel	CP high or low beam on alternate scans	RF interface box: CP high (or low) beam {relocated DC7 into RF interface box}

Table 1
(Continued)

ASR-9 Source			WSP
Functional Name	**Signal Name**	**Part Name /Tie Point**	**Part Name /Tie Point**
RF Test Target Generator(s)	RF test target generator	Linear "A", "B", & CP	Used off-line as in ASR-9
RF-IF TTG			TBD
Selected COHO	COHOSP	A3S2-J4 (COHO module)	WSP Receiver & timing
Linear "A" - high or low beam selection	BEAMONLOI +/- & BEAMONHI +/-	2A4A120: A61/A62 & A63/A64	Matrix control
Linear "B" - high or low beam selection	BEAMONLOI +/- & BEAMONHI +/-	5A4A120: A61/A62 & A63/A64	Matrix control
Circular - high or low beam selection	BEAMONLOI +/-	A5J11: Pins 2 & 20	RDA Controller
Polarization Selection - Linear or Circular	SBLP/CPA-	A4A121: C27	RDA Controller
Channel "A" or "B" selection	WXCHA-/B	A4A121: C80	ASR-9
ASR-9 2/6 Level automatic weather selection	WXSEL2-/6 or WXSEL2/6-	Card #217: A61 A62	TBD
Selected ACP Synchronized		BNC A5J1	To WSP processor
Selected ARP Synchronized		BNC A5J2	To WSP processor
10.35 MHz clock	Test Signal	A4A114: A16/A17(+/-)	Timing and control
5.1 MHz clock	PLL5.1MHZ	A4A114: C29	Timing and control
2.6 MHz clock	PLL2.6MHZ	A4A114: C26	Timing and control
Range clock (1.3 MHz)	SA1.3TSTGTS(+/-)	A4A120: A58/A59	Timing and control
RF Drive (Mod gate)	RGRFDRIVE-.	A4A122: A74	Reference
Pretrigger	PRETO	A4A120: C72	Timing and control

Table 1
(Continued)

ASR-9 Source			WSP
Functional Name	**Signal Name**	**Part Name /Tie Point**	**Part Name /Tie Point**
Transmit Time Trigger	RGPRETO-	A4A122: A82 REF.: 2.3.1.1.3.3.2.2.2	Timing and control
Range zero	RGRO-	A4A120: B75	Timing and control
Interrogate	INTERROGATE	A4A121: B76 Ref. 2.3.1.1.3.3.2.3	Timing and control
CPI start	RGCPIST-	A4A120: B81	Reference
CPI end	RGCPIEND-	A4A120: C81	Reference
Calibration trigger	RGCALTRIG-	A4A103: A22	TBD
Channel "A" - A to D output	ALTC100(+/-)	A4J135: 25/26 thru 47/48	Weather Processor RDA
Channel "B" - A to D output	ALTC200(+/-)	A4J136: 25/26 thru 47/48	Weather Processor RDA
Interface for 6 level weather less AP	CTS3(+/-)	Card #216: C12/C13 or Card #110: C54/C55	TBD
Interface for 6 level weather less AP	RTS3(+/-)	Card #216: C14/C15 or Card #110: A78/A79	TBD
Interface for 6 level weather less AP	RXD3(+/-)	Card #216: C16/C17 or Card #110: C52C53	TBD
Interface for 6 level weather less AP	TDX3(+/-)	Card #216: C18/C19 or Card #110: A81/A82	TBD

The following paragraphs provide details on to ASR-9 timing, reference and digital signal interconnections.

4.2.1 Active Channel Stable Local

The ASR-9 STALO selected by the on-line target channel is used and is connected directly to the mixer of the ASR-9 weather channel and will be used in place by the WSP.

4.2.2 COHO

The COHO is available on A352-J4 (COHOSP) at +2dBm level.

4.2.3 Azimuth Reference for the WSP

The ASR-9 derives its azimuth reference from one of the two pulse generators (with one on-line) located on the antenna pedestal. A train of 4096 azimuth change pulses are generated per revolution of the antenna, and a reference pulse is generated as the antenna passes north. In WSP operation it is desirable to initiate azimuth scan data processing at different locations to prevent missing data as the WSP switches between high and low beam during alternate scans of operation. The switching transient takes several milliseconds and the associated loss of data negates using one extended processing interval at the same azimuth location. The start-of-scan for the WSP processing is advanced 75 CPIP per revolution of the antenna, thus assuring that no azimuth region will have a recurring loss of data. See Table 2. This results in the loss of one Extended Coherent Processing Interval (ECPI) per scan.

Selection of which azimuth pulse generator is used for processing is determined by the ASR-9.

Table 2
Beam Switching Progression
for WSP Controlled Microwave Switches

"Scan"	Start Sector (and Azimuth)	Stop Sector	Sectors Processed	Beam Switch Position
0	0 (0.0)	74	0-255 0-74	Low
1	75 (105.5)	149	75-255 0-149	High
2	150 (210.9)	224	150-255 0-224	Low
3	225 (316.4)	43	225-255 0-255 0-43	High
4	44 (61.9)	118	44-255 0-118	Low
5	119 (167.3)	193	119-255 0-193	High
• • •	------------------	------------------	------------------	------------------
253	31 (43.6)	105	31-255 0-105	High
254	106 (149.1)	180	106-255 0-180	Low
255	181 (254.5)	255	181-255 0-255	High

4.2.3.1 Azimuth Change Pulse (ACP) Connection

The Azimuth Change Pulse appears at the rear of the card cage on the STU trigger amplifier (A4A221) pin 6. A more convenient location to acquire the signal is at the BNC connector on A5J1 in the top of the four-bay cabinet. The signal is an 85.3 Hertz pulse and is 0 to +15 into 75 ohms. The driver schematic for this signal can be found in ASR-9 TI6310.28, figure 11-8, page 8 of 17.

4.2.3.2 Azimuth Reference Pulse Generator

The Azimuth Reference Pulse (ARP) appears at the rear of a card cage on STU trigger amplifier A4A221 pin 27. A more convenient location to acquire this signal is at the BNC connector A5J2 in the top of the four-bay cabinet. The ARP which occurs as the antenna beam passes through north is 0 to +15 volts into 75 ohms. The driver schematic can be found in ASR-9 Technical Instruction Manual TI6310.28, Figure 11-8, Page 8 of 17.

The description for both signals can be found on Page 2-286 of Volume 4 of the ASR Technical Instruction Manual TI6310.28.

4.2.4 Connection to the Target Channel A/D Converters

Data for WSP operation are obtained from the target channel A/D converters for computation of linear polarized six-level weather from the range of the RAG controlled high/low transition (about 15 nmi) to the maximum 60 nmi range of the radar. In addition, the target channel A/D converters from the co-polarized outputs from the antenna feeds provide data used when operating with circular polarization to calculate the co-polarized component of weather intensity over the same range interval. When operating with circular polarization, co-polarized intensity values represent the depolarized signal component owing to differential phase shift resulting from passing through rain and from reflection by non-spherical precipitation particles. Using the sum of the squares formula, the co-polarized signal intensity values will be combined with the polarized signal intensity to obtain estimates of the total reflected power.

The A/D converter signals selected on an operating-channel basis are obtained from A4J135 (channel "A") and A4J136 (channel "B") located in the ASR-9 weather channel bay four. Refer to Technical Instruction Manual TI6310.28, Figure 11-16, Page 1 of 9.

4.2.5 Basic Clock Generation

The ASR-9 generates three basic clock pulses at frequencies of 10.35, 5.18, and 2.6 MHz. All clocks are in phase with the 2.6 MHz reference from the on-line target channel, receiver/processor (A or B). The ASR-9 weather and WSP channel basic clock generation functions are synchronized to the on-line channel. All three clock frequencies are fed into the staggered gate generation function which outputs the staggered gate pulses at frequencies of 0.65, 1.3, 2.6, and 5.18 megahertz for use in the weather channel and elsewhere in the system as clock data and synchronous enable signals. Signals as needed will be used by the WSP (Reference: (2.3.1.1.1.1) TI6310.36)

4.2.6 Rejection of Range Ambiguous Weather Echoes by Microstagger

An important feature of the WSP is its ability to reject second trip or range ambiguous weather echoes by taking advantage of microstagger operation implemented by the ASR-9 to eliminate range ambiguous aircraft echoes. It works effectively against rain clutter by decorrelating second trip echoes by incrementing the pulse repetition interval two or three range cells per pulse repetition interval.

The timing and control circuits of the system automatically set up sampling of the weather channel to correspond to the transmitted pulse offset. This function is referred to in the TI manual (TI6310.28) as "variable timing" and is found in Section 2.3.1.1.3.3.2.2. Currently, all operational ASR-9 systems are using variable timing. There is no action required for integrating/operating the features with the WSP.

4.2.7 Coherent Processing Interval

The ASR-9 coherent processing interval pair (CPIP) is the fundamental target data processing interval based on the time required for the antenna to rotate 1.4 degrees. During this time, the aforementioned group of ten high-PRF and eight low-PRF pulses is radiated and signals are received. A CPIP occurs every 16 azimuth change pulses (ACP) yielding 256 CPIPs during one rotation of the antenna. A comparable function will be derived directly by the WSP.

4.2.7.1 Trigger Pulse Generation (TPG)

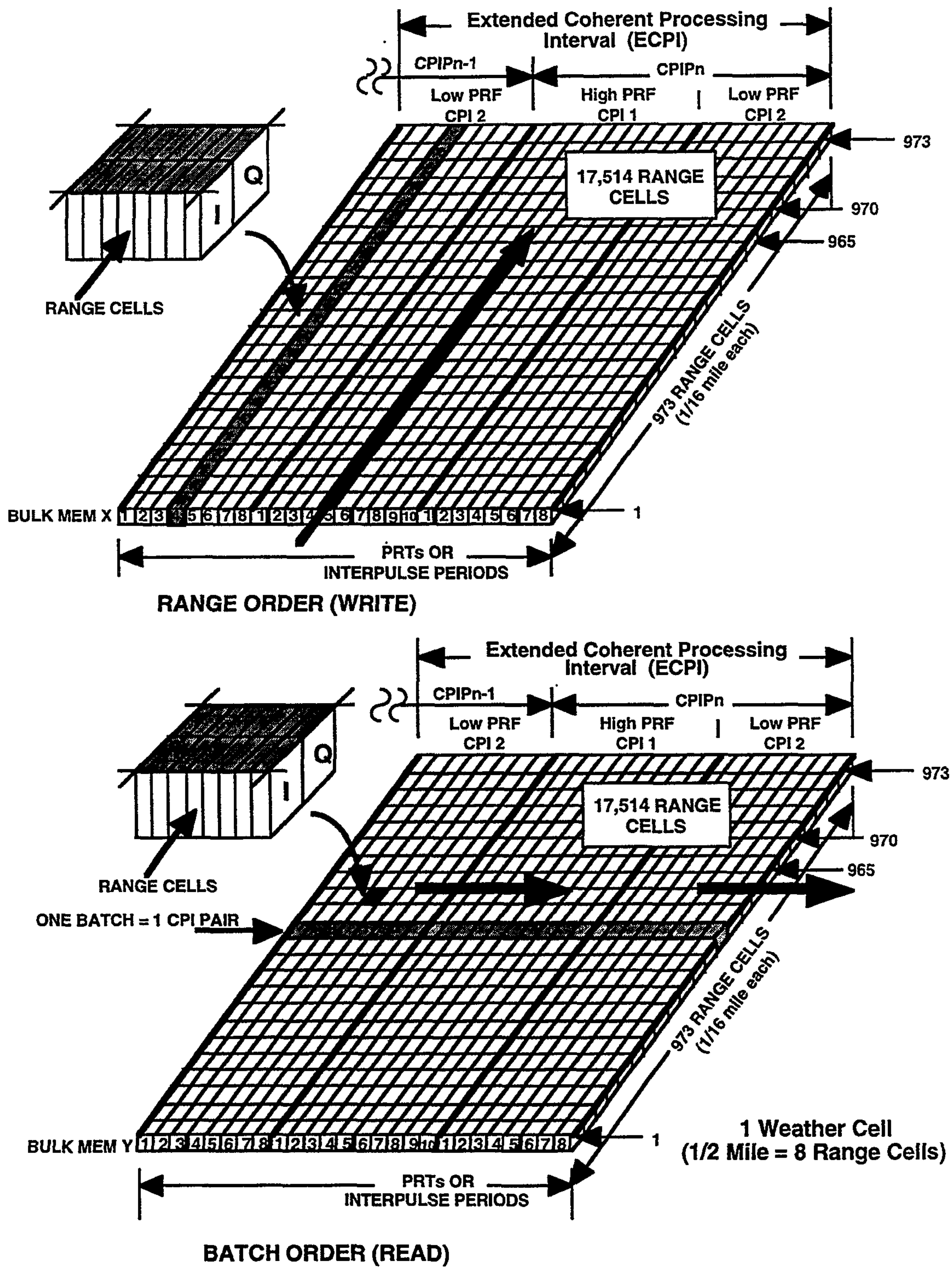
The 16^{th} ACP gate trigger initiates the generation of the CPIP and time intervals within the CPIP as well as the start of receiver events that occur within the CPIP. The trigger pulse timing is determined by a site-dependent pair of pulse repetition frequencies which are VSPs assigned by the frequency manager and implemented at the time of installation. For a particular PRF set, the trigger generator automatically varies the pulse repetition interval (microstagger) to eliminate range-ambiguous targets. The variable-rate timing is implemented using numbers which are stored on the RAG, generator memory board. The ACP gate trigger synchronizes the trigger output pulses to the real-time azimuth position of the antenna. A real-time binary count of range cells which occurs within each pulse repetition time (PRT) is also provided by the trigger pulse generation function. There are 18 or more PRTs in a CPIP, depending on the rotation rate of the antenna. Should the antenna speed slow down due to wind loading, up to three fill pulses at the high-pulse repetition frequency of the CPIP are used to fill the gap. Should the antenna speed up significantly, a "short" PRT is used to create 18 pulses in the CPIP without fill pulses.

Within each PRT, the ASR-9 processes date in 1/16 nmi increments, referred to as "range cells" (a total of 973 cells corresponding to $60\frac{13}{16}$ nautical miles are used). The last 13 cells are carried to provide data for the constant false-alarm rate function in the target processor.

The WSP employs 27 pulses in its coherent processing interval (Figure 13) and therefore uses a ring-buffer to acquire and store the quantized receiver data. It recovers eight pulses from the previous block, independent of the presence of fill pulses. The data are stored on a range-ordered basis for the 27 PRIs and read into the signal processor in batch order, i.e., 27 PRIs, one range at a time.

4.2.7.1.1 A/D Data Manipulation

The read-write algorithm used by the two-block, 18-pulse data structure of the ASR-9 target channel processor is transformed into a three-block, 27-pulse data analogue for the WSP. The write order distributes I and Q data for 973 range cells each pulse repetition interval. The WSP stores range-ordered data continuously. The high and low CPIs operate with two different pulse repetition frequencies to eliminate Doppler blind speed effects in the target detection. This arrangement, which accomodates the need of the target channel and the requirement of processing 27 PRIs for the WSP extended coherent processing interval, establishes a batch order as shown in Figure 13.



Modified TI 6310.28, Figure 2-33, Page 2-147

Figure 13. Read and write order of digital samples showing both the CPIP and ECIP array.

4.3 Control Functions

As described previously, the WSP RDA controls a network of microwave switches which route appropriate signals to the WSP receive chain. When on-line, the WSP must determine the appropriate positions for these switches using high speed logic devices, and generate suitable drive signals. The sequencing of signals processed by the WSP RDP is summarized in Figure 14. Special timing signals are provided for implementing the required switching of the microwave circuits and digital signals. The ASR-9 functions are described in ASR-9 Technical Instruction Manual TI6310.28 and will covered here only as they relate to their role in the WSP.

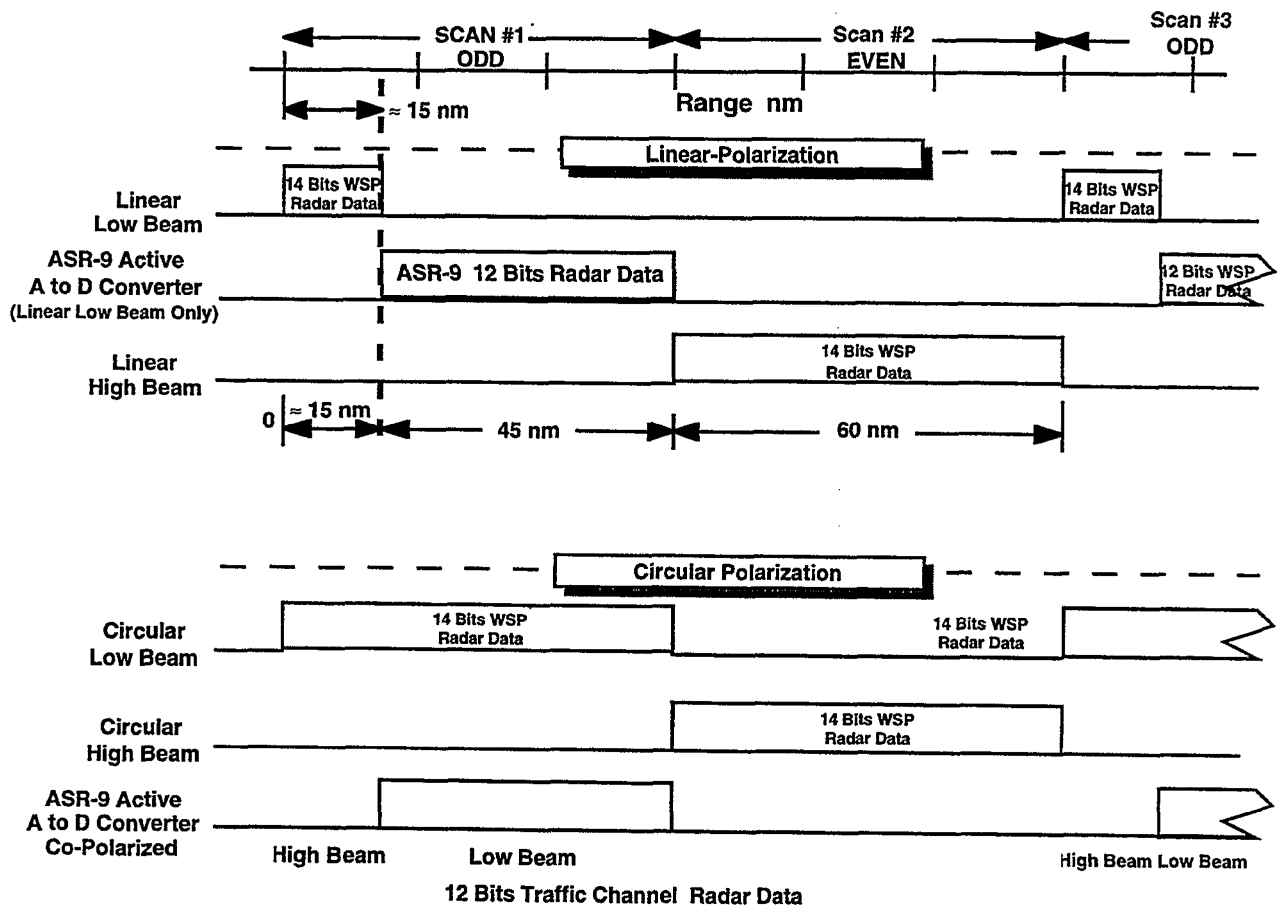


Figure 14. Timing diagram showing primary and secondary inputs into WSP radar data processor.

The RDA must also control an STC unit dedicated to the WSP input paths. The WSP must recognize when it has entered either a "fault" or "off-line" state, and return control of those switches embedded within the ASR-9 to that system.

4.3.1 On-Line Channel Selection

Beam switches XSW103 and XSW104 (see Figure 10) are under WSP control to provide WSP access to the active channel ("A" or "B"), co-polarized (target channel) microwave signals.

4.3.2 Target Channel Low Beam Selection

Beam switches XSW101 ("A" channel) and XSW102 ("B" channel) are controlled to provide WSP access to the active channel, co-polarized, low beam microwave signals. The control signals are slaved to the active channel RAG beam select signal so as to divert low beam data to the WSP only when it is not in use by the target channel. The waveguide is connected to the ASR-9 in the default condition.

4.3.3 ASR-9 Weather Channel Beam Switch

Control of the ASR-9 weather channel's coaxial beam switch (10A1S1) is assumed by the WSP when on-line in the CP mode. As opposed to the fast, RAG switching commanded by the ASR-9 weather channel, the WSP toggles this switch between high and low beams on an "alternating" scan basis as described below.

4.3.4 WSP Receiver Input Control (SP3T)

The single-pole, triple throw switch XSW105 is controlled by the RDA to select the appropriate microwave input to the WSP receive chain. During CP transmission, this switch is latched to the output of the cross-polarized channel coaxial switch (10A1S1). During LP transmission, the switch toggles–on an alternating scan basis–between the high and low beam inputs from the target channel microwave paths.

4.3.5 Timing and Control of Alternate Beam Switching

The operation of the WSP with alternating scan beam switching and a single receiver channel requires dedicated timing circuitry in which the antenna change pulses (ACPs) and antenna reference pulses (ARPs), suitably processed, play a key role in controlling the above microwave switch functions.

4.3.5.1 Scan Initiation Stepping

The WSP timing unit will receive input signals from the antenna reference pulse (ARP) and antenna change pulse (ACP) circuits of the ASR-9. The transition between high and low beam takes place within a 1.4 degree interval (1/256 of a circle), defined, in the ASR-9, as a coherent processing interval pair (CPIP, approximately 20 milliseconds). Owing to the use of electromechanically driven microwave switches that transition in a few milliseconds, one extended coherent processing interval will be lost during each scan. To minimize repeatedly missing critical data at the same location, the position of the alternating scan transition will be stepped in azimuth after each scan. The stepping interval is equal to 75 antenna azimuth beamwidths, or 105.5 degrees. The beam switching progression is described in Table 2.

The timing for the switching transitions for selection of the high and low beam will be synchronized to the corresponding beam position and radar transmission to assure that registration of the precipitation and clutter maps are preserved. It is not necessary to initialize the start of the above sequence at the Antenna Reference Position; any CPIP start pulse is appropriate to begin counting the 75 CPIP interval used to rotate the high-low beam transition.

4.3.6 Microwave "Preselector" Filter

Switches S5 and S6 are controlled by the WSP when on-line to select the microwave bandpass filter (FL3 or FL4) matched to the active channel transmitter frequency.

4.3.7 RF Receive Chain Output

As shown in figure 10, the RF receiving chain components of the ASR-9's six level weather channel are shared by the WSP. When on-line, the WSP RDA sets switch XSW107 to direct this output to the WSP's high dynamic range IF receiver.

4.3.8 Sensitivity Time Control Attenuator

The STC unit within the shared WSP/Six-Level Weather Channel RF train is controlled by the RDA when the WSP is on-line. As noted, the WSP normally employs significantly less attenuation than is used by the existing weather channel owing to the increased dynamic range of its IF receive chain and digitization circuits. The RDA controls the STC unit on a range-azimuth dependent basis using site-adaptable maps. Eight STC maps are employed to cover all combinations of polarization (CP or LP), active channel (A or B) and beam selection (high or low).

4.3.9 Six-Level Data Output Selection

The six-level weather feed to the local maintenance PPI display, and to controller's DEDS and BRITE display is switched to the on-line processor, i.e., either the WSP or the ASR-9 six-level output ports. The switch function is installed by cutting four wires on the backplane and installing appropriate SPDT logic to route either the WSP output, suitably formatted and controlled, or the original ASR-9 six-level weather data to the transmission circuits of the ASR-9. Refer to TI6310.36 card #216 and card #110, appendix X 645A196-1 rev. AG sheet #126 [RXD3T(+/-) and RTS (+/-)]. [Note: This reference is optional as there may be less invasive use of the backplane wiring. The above mentioned circuit revisions communicate only six-level weather information from the WSP or the ASR-9 weather channel to the controller's ARTS display processor via circuits MIP and SCIP already in place in the ASR-9. Separate circuits that combine the product generator outputs are used to feed the dedicated WSP display functions in the TRACON and the ATCT.]

4.3.10 "Off-line" or "Fault" Condition

If the WSP is placed off-line due to detection of a fault condition by its RMS, or through user manual action, microwave switches must be latched in appropriate positions and ASR-9 system control functions restored so that baseline ASR-9 system functions and operation are unaffected. These default switch positions shall correspond to the unenergized state. The following actions are required:

1. Switches XSW101 and XSW102 are latched so as to "hardwire" the same sense polarization low beam antenna outputs to the input of the target channel RAG beam switches (S2 and S3).

2. Control of the weather channel preselector switches (S5 and S6) and STC unit is returned to the ASR-9 six-level weather channel.

3. Switch XSW107 is latched so at to provide RF receive chain output to the existing ASR-9 six-level weather channel IF receiver, digitization and processing circuits.

4. Control of the cross-polarized signal coaxial waveguide switch (10A1S1) is returned to the ASR-9. This allows for resumption of the RAG beam selection mode required by the ASR-9 six-level weather channel.

5. The SP3T switch XSW105 is latched so as to hardwire the output of the cross-polarized coaxial waveguide switch (10A1S1) to the weather channel receiver.

6. Control of the six-level weather reflectivity feed to local maintenance, DEDS and BRITE displays is returned to the ASR-9 system.

4.4 Radar Data Processor (RDP) Input Synchronization

The output of the RDA to the RDP are uniformly formatted "pulse records," clocked over a parallel bus at a rate consistent with the range-gate sampling interval of the ASR-9 system. Figure 15 is a high-level block diagram of the digital interface used in the Lincoln Laboratory WSP prototype to interconnect the RDA and RDP functions. For each ASR-9 pulse-repetition interval (PRI), the VME digital interface (VDI) transmits a fixed length (32 bit) message onto a high-speed bus within the RDP. To create this message, the VDI performs minor reformatting of the fixed length message transmitted by the radar digital interface (RDI). The RDI-VDI message interface allows only 31 information bits per word because the most significant bit (bit 31) is used to identify the first word of a frame. The VDI messages are clocked into the RDP at a rate of 2.6M words per second.

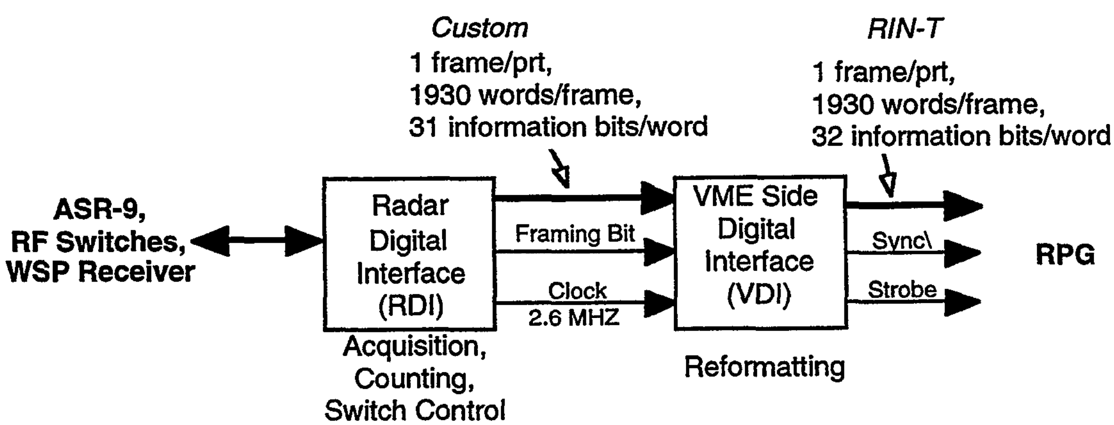


Figure 15. Lincoln Laboratory WSP Prototype RDA to RDP interface.

Table 3 identifies the data elements included in the message frames transmitted from the RDA to the RDP. To distinguish whether data are acquired from the ASR-9 system, or created within the WSP RDA, the source for each message element is indicated in the third column of the table.

Table 3
VDI-RPG Message Format

WORD	IDENTIFIER		SOURCE
0	Bits 3-0:	Year Ones	RDI
	Bits 7-4:	Year Tens	RDI
	Bits 15-8:	Drive ID (0x01)	RDI
	Bits 18-16:	XSW105 Status: 001 - LP, low beam; 010 - LP, high beam; 100 - CP	WSP RF Switch
	Bit 19:	XSW103 & 104 Status A=0, B=1	WSP RF Switch
	Bit 20:	Channel: A=0, B=1	ASR-9 Backplane
	Bit 21:	Polarization: L=1, CP=0	ASR-9 Backplane
	Bit 22:	Scan: even=0, odd=1	RDI
	Bit 23:	XSW107 Switch Position: 0=ASR-9, 1=WSP	RDI
	Bit 24:	STC Switch Position: 0=ASR-9, 1=WSP	RDI
	Bits 30-25:	unused	
	Bit 31:	0	RDI
1, 2	Bit 30-0:	Fast Time Count (f = 1.3 Mhz)	RDI
	Bit 31:	0	
3	Bits 11-0:	Azimuth	RDI
	Bits 31-12:	0	
4	Bits 11-0:	Scan Count (increments every ARP)	RDI
	Bits 31-12:	0	
5	Bits 30-0:	Frame Count (increments every PRT)	RDI
	Bit 31:	0	
6	Bits 31-0:	Test Pattern 0x2AAA5555	RDI
7	Bits 31-0:	Test Pattern 0x5555AAAA	RDI
8	Bits 31-0:	Test Pattern 0x2AAA5555	RDI
9	Bits 31-0:	Test Pattern 0x5555AAAA	RDI
FOR 960 RANGE CELLS (range sample n = 0 through 959):			
10+2n	Bits 1-0:	0*	
	Bits 13-2:	Target Channel Linear I	ASR-9 backplane
	Bits 15-14:	0*	
	Bits 27-16:	Target Channel Linear Q	ASR-9 backplane
	Bits 28:	High or Low Beam (High=1)	ASR-9 backplane
	Bits 31-29:	0*	
11+2n	Bits 13-0:	WSP Receiver I	RDI A/D Converter
	Bits 27-14:	WSP Receiver Q	RDI A/D Converter
	Bits 31-28:	AGC(3:0)	WSP Receiver IAGC

* For each range cell, a total of 62 information bits are available in the Phase II prototype RDI-VDI interface. Of these, 25 bits are dedicated to the target channel I & Q bits and the High/Low beam indication bit. Therefore, 37 bits are available in each range cell to transfer the WSP receiver I & Q bits, AGC bits, and a saturation indicator.

5.0 SUMMARY

As discussed in this report, the required inputs to the WSP can be acquired from the ASR-9 through implementation of suitable microwave and digital signal interfaces, appropriately controlled by logic devices within the WSP. Although detailed design of this interface will be accomplished by the WSP implementation contractor, we expect that many features described herein will be preserved at least functionally.

Many, but not all, of the interface components described herein have been implemented and validated using the Lincoln Laboratory ASR-WSP testbed in Albuquerque, NM and Lexington, MA. Items that have not yet been installed on these WSP exploratory units include:

1. The recommended downconversion IF filter with instantaneous Automatic Gain Control calculated using data from the preceding PRI;
2. The interface hardware and software needed to feed WSP-generated six-level weather back into the ASR-9 system for output onto existing controllers' radar scopes;
3. Use of the RF test signals from the ASR-9,
4. Built-in failure sensing of the WSP,
5. BIT/FIT, and
6. RMS functions.

Implementation and evaluation of an appropriate IF receiver (item 1) and six-level weather feedback interface (item 2) are underway via a contract from Lincoln Laboratory to Northrop Grumman Corporation. In addition, some elements of WSP BIT/FIT and RMS functions are being developed for evaluation under this contract. These subsystems will be implemented on the WSP exploratory units and evaluated during the 1997 convective storm season. The remaining items listed above will be accomplished during WSP full-scale development.

ACRONYMS AND ABBREVIATIONS

A/D	Analog to Digital
ACP	Antenna Change Pulse
AGC	Automatic Gain Control
AGL	Above Ground Level
AP	Anomalous Propagation
ARP	Azimuth Reference Pulse
ASR-9	Airport Surveillance Radar
ATCBI	Air Traffic Control Beacon Target Interrogator
ATCT	Air Traffic Control Tower
BIT	Built-in Test
BIT/FIT	Built-in Test/Fault-Isolation Test
BNC	Bayonet Neill and Councelman connector
BRITE	Bright Radar Indicator Tower Equipment
CFAR	Constant False-Alarm Rate
CMT	Configuration, Monitor, and Test data bus
COHO	Coherent Local Oscillator
COTS	Commercial Off-The-Shelf
CP	Circularly Polarized, Circular Polarization
CPI	Coherent Processing Interval
CPIENO	End of CPI
CPIP	Coherent Processing Interval Pair
DEDS	Data Entry and Display System
DF	Display Function
DRI	Data Recorder Interface
ECPI	Extended Coherent Processing Interval
EEPROM	Electrically Erasable Programmable Read-Only Memory
FAA	Federal Aviation Administration
GPS	Global Positioning System
I&Q	In phase and Quadrature
IAGC	Instantaneous Automatic Gain Control
IF	Intermediate Frequency
LED	Light Emitting Diode
LNA	Low Noise Amplifier
LP	Linearly Polarized, Linear Polarization
MDS	Minimum Detectable Signal
MIP	Message Interface Processor
MTD	Moving Target Detector
NAS	National Airspace System
NIMS	National Airspace System Infrastructure Monitoring System
PLL	Phase Locked Loop
PPI	Plan Position Indicator
PRETO	Pretrigger 0
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
PRT	Pulse Repetition Time
RAG	Range Azimuth Gate

RDA	Radar Data Acquisition
RDI	Radar Digital Interface
RDP	Radar Data Processor
RDT	Ribbon Display Terminal (an alphanumeric display)
RF	Radio Frequency
RF-IF	Radio Frequency-Intermediate Frequency
RGPRETO	Range Pretrigger
RMS	Remote Monitoring System
RPG	Radar Product Generator
SCIP	Surveillance Communications Interface Processor
SCSI	Small Computer Systems Interface
SD	Situation Display
SP3T	Single-Pole, Triple-Throw
SPDT	Single-Pole, Double-Throw
STALO	Stable Local Oscillator
STC	Sensitivity Time Control
STU	System Timing Unit
TDWR	Terminal Doppler Weather Radar
TPG	Trigger Pulse Generation
TRACON	Terminal Radar Control Facility
TTG	Test Target Generator
VDI	VME-Data Interface
VME	An IEEE standard chassis backplane
VSP	Variable Site Parameters
WSP	Weather Systems Processor

REFERENCE

[1] Mark E. Weber, "ASR Weather Systems Processor (WSP) Signal Processing Algorithms," Lexington, MA, MIT Lincoln Laboratory, Project Report ATC-255, publication pending.

APPENDIX
SUPPLEMENTAL MATERIAL
ON THE ASR-9 SIX-LEVEL WEATHER CHANNEL

The following paragraphs provide supplemental information on six-level weather processor functions. Where provided, the parenthetical numbers in the sub-section headings refer to the ASR-9 Technical Instruction Manual paragraph where the associated function is described.

A. ASR-9 Six-Level Weather Receiver/Processor Monitoring

In the original ASR-9 configuration, the six-level weather data are generated in a subsystem which includes the weather channel low-noise amplifier, a superheterodyne receiver, digital converters, a digital processor, and processes diagnostics and VSPs from the Remote Monitoring Subsystem (RMS) and azimuth data (ACP and ARP) from the antenna. The monitoring and control functions associated with the ASR-9 distribute VSPs to the timing unit (synchronizer, filtering and magnitude function, and to the six-level detection functions). In addition to the monitoring and control functions, a set of BIT/FIT functions are implemented in the ASR-9 six-level weather processor. The weather receiver cabinet (Number 4) also contains switches and light emitting diodes (LEDs) which are used by maintenance personnel at the site. A local display processor function is implemented to feed a maintenance display unit also located at the local radar site. Figure 6, the weather receiver/SCIP overview block diagram, contains the major functional elements and signal flows to and from the weather channel.

The following functions are performed by the ASR-9: a) calibration batch data processing, b) weather data processing, and c) BIT batch data processing. The BIT functions are all performed during the dead time preceding the next PRI. The synchronizer function initializes a routine that checks the RF-IF receiver, the filtering and magnitude function, and the monitoring and control function. The batch data processing is a test mode initialized by the remote monitoring system and is transparent to operation of the RF-IF receiver.

B. Master Timing

The synchronizer is the primary source of timing signals for the entire ASR-9. In addition to providing all the master clock signals used both by the target and weather channels, it implements the following:

The system timing unit (Table A-1) develops various clocks, selects the antenna high/low beam horn, and performs BIT for the synchronizer. The BIT function tests the trigger signals from the RF test target generator A4A125, the range azimuth generator (A4A122), the STC/calibration generator (A4A123), and the batch control sequencer A4A117. The BIT test information is routed to the monitoring and control function. There the configuration, monitor, and test data bus (CMT), the range azimuth gate generator (A4A122), and the triggers generated by the RAG are used in conjunction with the system timing unit A (A4A120) and the RF test generator (A4A124) in the RAG generation to determine system status. In addition, some of the triggers are also used in the filtering and magnitude process and in the target signal processor, weather receiver/SCIP, and the two-level weather detector. The triggers are tested by the BIT circuitry located in the STU A (A4A120). The RAG generator also contains the function that synchronizes the antenna position pulses with range sample pulses. The function of the STU B (A4A121) is to provide an interface between the transmitter, RF/if receiver, frequency generator, weather receiver/SCIP, and the monitoring control function. The STU B receives radar mode data from the weather receiver/SCIP and uses this data to generate control signals that are output to the transmitter. It also receives buffered triggers from the RAG generator and outputs them to the transmitter. One of these is a pre-trigger which generates program delay triggers used for system alignment. The STU B also outputs system control signals to the RF-IF receiver and data processing controls to the two-level weather detector. Some of the signals generated on STU B are tested on BIT located in STU A.

Table A-1
ASR-9 Timing and Test Functions

Name Designation	Abbreviated Name	Reference *
Batch Control Sequencer	BCS	A4A117
PLL channel Sync. PLL channel Sync.	PLL	A4A114
System Timing Unit A	STUA	A4A120
System Timing Unit B	STUB	A4A121
RAG	RAG	A4A122
STC/calibration generator	STC/CAL	A4A123
RF Test Target Generator	TTG	A4A124

* Refers to ASR-9 circuit card designation

C. STC/Calibration Generator (A4A123)

The STC/Calibration Generator provides signals that control receiver gain during the live time and generates calibration control signals during the calibrate time. Both RF and IF calibration signals are generated during the calibrate time. The IF signals are generated by the RF-IF receiver while the RF test signals are generated by the RF test target generator (A4A124). A control signal is also produced which controls the sampling of the test target data for the filtering and magnitude processor. The STC/Calibration Generator is controlled by the monitoring and control function via the CMT bus. This unit's outputs are tested by BIT located on STU A.

D. Weather Test Target Generator (A4A124)

The weather test target generator provides two- and six-level weather digital signals. Target signals are used for testing the target receiver/processor in the A and B channels. The weather digital test target signals are synchronized with the RF test target data by the target A and target B signals from the target receiver/processors. The board also receives channel control signals (CHA-/B) from the local system control processor to produce RF and IF control signals. These signals are output to target receiver/processor A and B, the RF filters, and the RF-IF receiver. BIT testing of the test target generator board signals is performed on the STU A board. The test target generator is controlled by the monitoring and control function board via the CMT data bus.

E. A/D Interrogate Pulse Generation (2.3.1.1.1.5)

The A/D pulse function is used on the ASR-9 A/D converter board of the RF-IF receiver for A/D interrogations. The PRT start triggers PRETO. RGPRETO enables the output of the interrogate signal INTERROGATE. A similar function is required for the WSP.

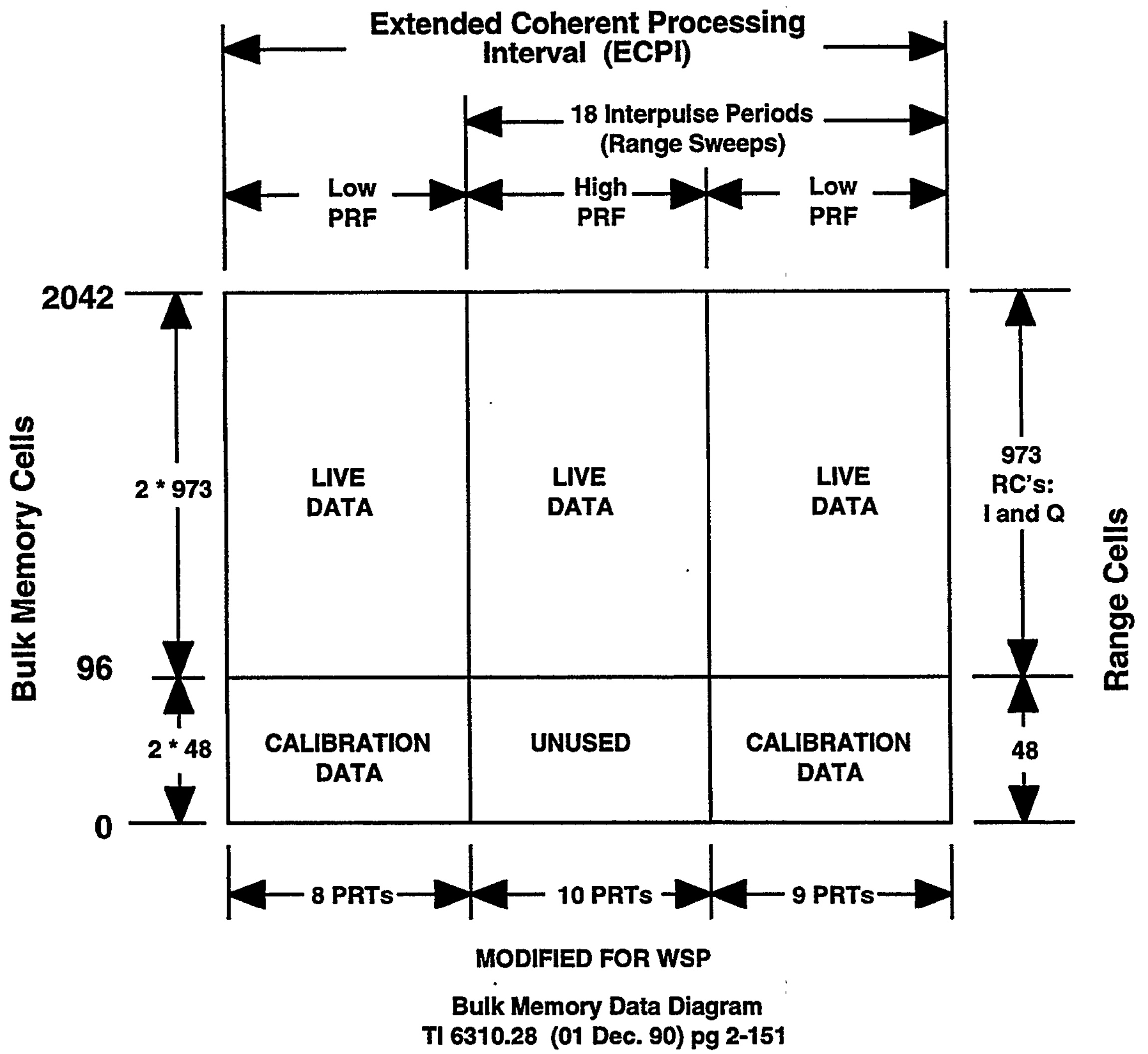
Because of the need to have a fine adjustment of the INTERROGATE while maintaining its phase synchronization with the radar timing, a 10.35 MHz clock shifts the 1.3 MHz pulses through a delay register to maintain phase for every PRT.

F. Batch Control Sequence Generation (2.3.1.1.1.6)

The batch control generates a series of signals that sequentially order the flow of weather data, commencing at the filter and magnitude processor and proceeding all through six-level weather detector/processor functions. A batch of data includes the weather, test, and calibration data processed during one CPIP. The batch control signals are structured by a pre-programmed memory in the batch control sequence. The process is started by the CPIP start trigger from a trigger pulse generator. BIT/FIT logic signals are scheduled by this process (See Figure A-1). Figure A-1 illustrates the memory requirements associated with a CPIP.

G. Batch Timing Signals Synchronization (2.3.1.1.1.7)

The batch time signals synchronization function develops the antenna polarization flag (circular or linear) and the north indicator (antenna at zero degrees, and the level of weather flag). The ASR-9 six-level weather detector uses batch time signals to select pre-programmed VSPs that define weather detection threshold values in the ASR-9 Wx channel. The batch time CPIP clock which is enabled by the CPIP start trigger from the trigger pulse generator function synchronizes the batch time signals to the batch processing.



WSP bulk memory located in the Radar Data Acquisition unit.

Figure A-1. Bulk memory diagram showing the 960 weather target range cells, the 13 CFAR cells used by the target channel, and the nominal 48 range cells used for calibration signals.

H. Receiver Calibration High/Low Beam Control

During normal operation of the radar, calibration of the receiver and the A/D converter are constantly being performed by the monitoring and control function. Details are found in TI manual TI6310.28.

I. Receiver Control and Test Tone Generator[1]

In the ASR-9 weather channel, the RF-to-IF conversion is coupled through an isolator and amplifier to provide input matching. The overall noise figure of the front end is 6 dB. The amplified RF is applied to a 90-degree hybrid, a part of an image generation and image rejection

[1] The circuit will be modified with the direct digital conversion circuit.

scheme. The image signal is effectively canceled by the hybrid arrangement and subsequent mixers. The overall gain of the RF receiver is 14 dB, plus or minus 1.4 dB.

The ASR-9 amplifier has an AGC attenuator at the output of its first stage which is controlled by the digital processor via a D/A converter to maintain constant gain and hold the receiver output noise at a constant level. In addition to this feature, the ASR-9 receiver has a limiter circuit inserted between the third and fourth IF amplifiers to limit the peak amplitude of the receive signal to prevent A/D saturation. The limiter is adjustable to within ± 2 dB with respect to the signal level that saturates the A/D converter. There are three stages involved in the AGC amplifier. The fourth stage is used to boost the signal to the level required by the A/D converter. The output of the fourth stage is applied to a phase detector input through the bandpass filter and finally by its amplifiers. The overall bandpass is set to 923 kilohertz at the -60 dB point corresponding to the transmitter pulse phase characteristics.

Receiver calibration data is sent to the RF-IF receiver function from the synchronizer circuits. The test functions include setting the AGC of the receiver and regulating the I&Q amplitude phase balance and DC offset. The test tone signal is also controlled by this function. The test tone supplied from the active target channel via J1-D is used for testing the circuit.

J. I&Q Development

A very comprehensively designed I&Q detector is used in the ASR-9 weather channel. The description of the ASR-9 I&Q circuitry is found on page 2-137 of TI 6310.28.

A coarse and fine digital conversion scheme is used to produce the 12-bit I&Q words used in the weather channel. The ASR-9 weather channel provides A/D converter testing, a three-point test to verify that the circuit is operating at specified levels, and a monotonicity test for the A/D converter. Similar test functions may be applied to circuits in the WSP.

Analog data are derived from a logarithmic conversion of the sixth IF amplifier output video. Timing for the D/A converter is provided by the receiver control (reference TI 6310.28, page 2-137). The I&Q video signals are connected through the analog switch to sample and hold networks. Signals are appropriately amplified and sent on to the maintenance display.