12B.4 ASR-9 WEATHER SYSTEMS PROCESSOR TECHNOLOGY REFRESH AND UPGRADE

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1. ABSTRACT

The Weather Systems Processor (WSP) is an add-on system to the Airport Surveillance Radar-9 (ASR-9) that generates wind-shear detection and storm-tracking products for the terminal airspace. As the original system ages and pre-purchased replacement parts in the depot are used up, it becomes increasingly problematic to procure hardware components for repairs. Thus, a technology refresh is needed to sustain WSP operations into the future. This project targets the radar data acquisition (RDA) and radar data processor (RDP) subsystems for replacement by updated hardware and software. At the same time, the increase in computational capability allows for an upgrade in the processing algorithms, which will lead to data quality improvements and better wind-shear detection performance.

2. BACKGROUND

Low-altitude wind shear, especially a microburst, is hazardous to aircraft departing or approaching an airport. The danger became clear in a series of fatal commercial airliner accidents in the 1970s and 1980s. In response, the Federal Aviation Agency (FAA) commissioned and deployed three ground-based low-altitude wind-shear detection systems—the Low Level Wind Shear Alert System (LLWAS), the Terminal Doppler Weather Radar (TDWR), and the ASR-9 WSP (Weber and Stone 1995). Since the deployment of these sensors, commercial aircraft wind-shear accidents have dropped to near zero in the U.S. This dramatic decrease in wind-shear accidents confirms the safety benefits provided by these detection systems. Furthermore, the broad-area observation capability of the TDWR and WSP yields delay reduction benefits (Evans and Weber 2000), e.g., through the forecast of airport wind shifts that require runway reconfigurations.

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As an add-on processing system, the WSP was significantly cheaper than the TDWR to develop, acquire, and maintain. However, because the ASR-9 is not a weather radar, the wind-shear detection performance of the WSP is not quite as good as that of the TDWR. Therefore, TDWRs were deployed at 45 major terminals with the most exposure to microbursts, and WSPs were installed at 34 ASR-9-equipped airports with lower probabilities of convective wind-shear events. Figure 1 shows the map of WSP locations.

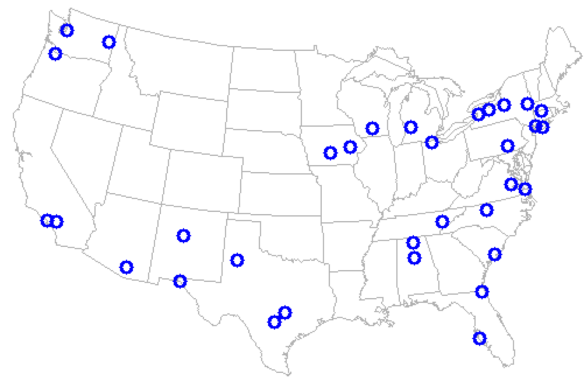

Figure 1. Map of ASR-9 WSP sites. Honolulu is another WSP airport but is not shown here.

The two main drawbacks for weather observation with an ASR-9 are its antenna's broad cosecant-squared-pattern beam that limits the vertical resolution and rapid rotation rate that constrains the length of the coherent processing interval (CPI). Table 1 provides some relevant ASR-9 characteristics.

Frequency Band	2.7–2.9 GHz
Peak Power	1.1 MW
Pulse Width	1 μs
Antenna Gain	34/33 dB (low/high beam)
Antenna Beamwidth	1.4° (Az.), 4.8° (El.)
Antenna Rotation Rate	75° s^{-1}
Pulse Repetition Interval	817–1200 μs

Table 1. ASR-9 Parameters

The ASR-9 has a reflector antenna with two feed horns. The horns have associated gain patterns that overlap but are displaced in elevation angle. The low beam is always used for transmission, whereas both beams are used on reception. For aircraft surveillance, the high-beam receive channel is used at short range (to ~26 km) in order to reduce ground clutter interference. The low-beam receive signal is used at farther ranges to maintain low altitude coverage. The ASR-9 also has the capability to transmit either vertically polarized or right-hand circularly polarized signals. On reception, both co-polarized and cross-polarized signals are available. The linear mode is used during clear weather. When significant precipitation is detected in the coverage area, the polarization is switched to circular mode in order to reduce weather clutter in the target channel.

Although the ASR-9 has a built-in weather receiver channel (Figure 2), its dynamic range is not wide enough for near-range low-altitude wind-shear measurements. Therefore, for the WSP, the built-in weather channel hardware was replaced with a receiver chain more suited for this purpose. Additional radio frequency (RF) plumbing was also installed (Saia et al. 1997) in order for the upgraded weather receiver to access signals from the antenna regardless of the radar's polarization mode (Figure 3). However, since the WSP has only one receiver, its input is switched between the low and high beams after each scan. The WSP low-beam weather sensitivity is -3 dBZ at 10 km.

The original WSP was developed by MIT Lincoln Laboratory (LL), Sigmet (now part of Vaisala Inc.), and

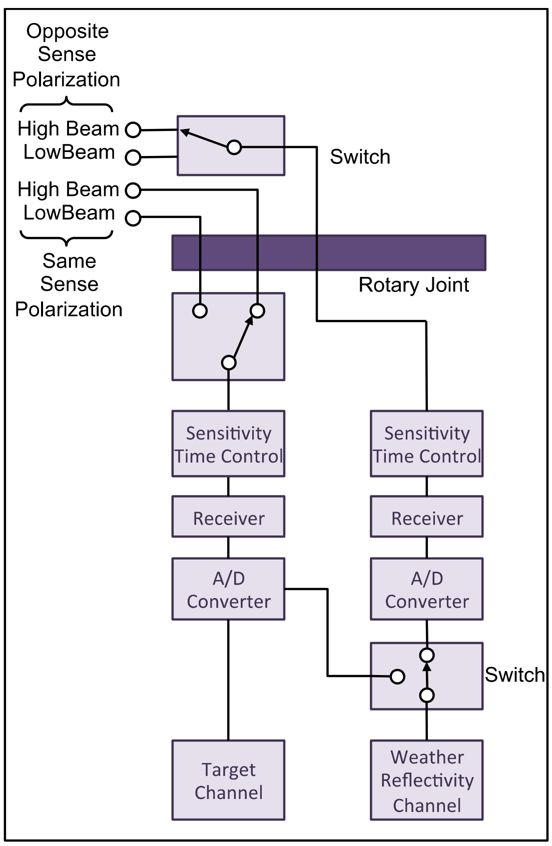

Figure 2. Block diagram of ASR-9 target and weather receiver chains without WSP (Weber and Noyes 1989).

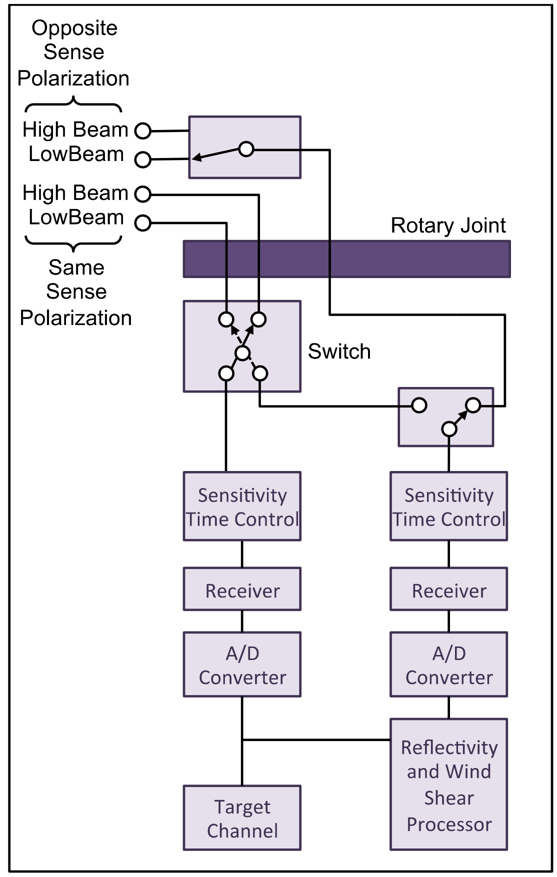

Figure 3. Block diagram of ASR-9 target and weather receiver chains with WSP (Weber and Noyes 1989).

Northrop Grumman from the late 1980s into the 1990s. As the FAA wanted to have a form-fit-function replacement for the technology refresh, it was decided that a renewed partnership between MIT LL and Vaisala would be the most effective and efficient way to proceed.

3. TECHNOLOGY REFRESH AND UPGRADE

Since the completion of WSP deployment, some of its parts have become obsolete. Although spares were purchased up front and stored in the FAA's depot, these are also starting to run out. Thus, there is now a real danger to continued operations from the inability to replace broken parts. The primary goal of this project is to replace the outdated hardware with more sustainable, open-system, commercial off-the-shelf (COTS) components.

Figure 4 shows the block diagram of the current WSP (Newell 2000). The RDA is composed of an intermediate frequency digital receiver (IFDR) and a custom radar interface module (RIM). In-phase and quadrature (I&Q) time series data are sent from the RDA to the VME-bus-based RDP, where Mercury Computer Systems Power PC digital signal processors (DSPs) generate base data for the FORCE Computer Systems SPARC boards to turn into wind-shear detection and other weather products.

The technology refresh will proceed in two phases. In the first phase (Figure 5), the IFDR will be upgraded to the latest model (RVP-901) from Vaisala (a form-fit-function replacement). This will increase the instantaneous dynamic range of the I&Q data from 83 dB to 95 dB. In the legacy WSP, the dynamic range limiter is the IFDR, but with the upgrade the constraint will be the 95-dB dynamic range of the low-noise amplifier (LNA) in front of the IFDR. The added dynamic range will improve the ability of the WSP to observe weak gust-front and microburst outflow signatures embedded in strong ground clutter.

In Phase 1, the DSP and data recording functions will be moved from the RDP to a Linux server in the RDA. The RIM will be replaced by an interface panel (Vaisala RCP-903), and the global positioning system (GPS) receiver in the RDP rack will be replaced by a GPS-based network time protocol (NTP) server connected to the RDA Linux computer via Ethernet. The goal of this phase is to refresh the most unsustainable parts (IFDR, RIM, Mercury boards, and the data recording drives).

In Phase 2, the VME-bus chassis will be eliminated altogether, with the weather product generation functionality based in a Linux PC. In the end, the number of line replacement units (LRUs) will fall from sixteen to five, making maintenance simpler and future software upgrades more straightforward. The only custom component will be the interface panel.

The increased processing power and memory of the refreshed WSP provides an opportunity for enhancing the DSP and weather product generation algorithms. Offline work on the former so far has yielded marked improvements in base data and dual-beam velocity estimate quality, with the ability to dealias velocity and filter out moving clutter targets that did not exist in the legacy system (Cho 2015).

4. SUMMARY

In an effort to maintain supportability, a technology refresh is being performed for the RDA and RDP subsystems of the ASR-9 WSP. The new hardware will improve the dynamic range, processing power, and memory capacity. Upgrades to the processing algorithms will enhance the output base data quality and wind-shear detection performance.

Development of the only new custom hardware (the ASR-9/WSP interface panel, RCP-903) is complete. The FAA has received five sets of the first-article RDA hardware (IFDR, interface panel, and Linux server), and integration testing with the Academy ASR-9 in Oklahoma City is ongoing. Software development for Phase 1 is nearing completion. Operational key-site testing and real-time implementation of the enhanced DSP algorithm are planned for FY2016. The Phase 2 schedule is still to be determined at this time.

5. REFERENCES

Cho, J. Y. N., 2015: Enhanced signal processing algorithms for the ASR-9 Weather Systems Processor. *J. Atmos. Oceanic Technol.*, **32**, 1847-1859.

Evans, J. E., and M. E. Weber, 2000: Weather radar development and application programs. *Linc. Lab. J.*, **12**, 367-382.

Newell, O., 2000: ASR-9 Weather Systems Processor software overview. Project Rep. ATC-264, MIT Lincoln Laboratory, Lexington, MA, 83 pp.

Saia, J. J., M. L. Stone, and M. E. Weber, 1997: A description of the interfaces between the Weather Systems Processor (WSP) and the Airport Surveillance Radar (ASR-9). Project Rep. ATC-259, MIT Lincoln Laboratory, Lexington, MA, 58 pp.

Weber, M. E., and T. A. Noyes, 1989: Wind shear detection with airport surveillance radars. *Linc. Lab. J.*, **2**, 511-526.

——, and M. L. Stone, 1995: Low altitude wind shear detection using airport surveillance radars. *IEEE Aerosp. Electron. Syst. Mag.*, **10**, 3-9.

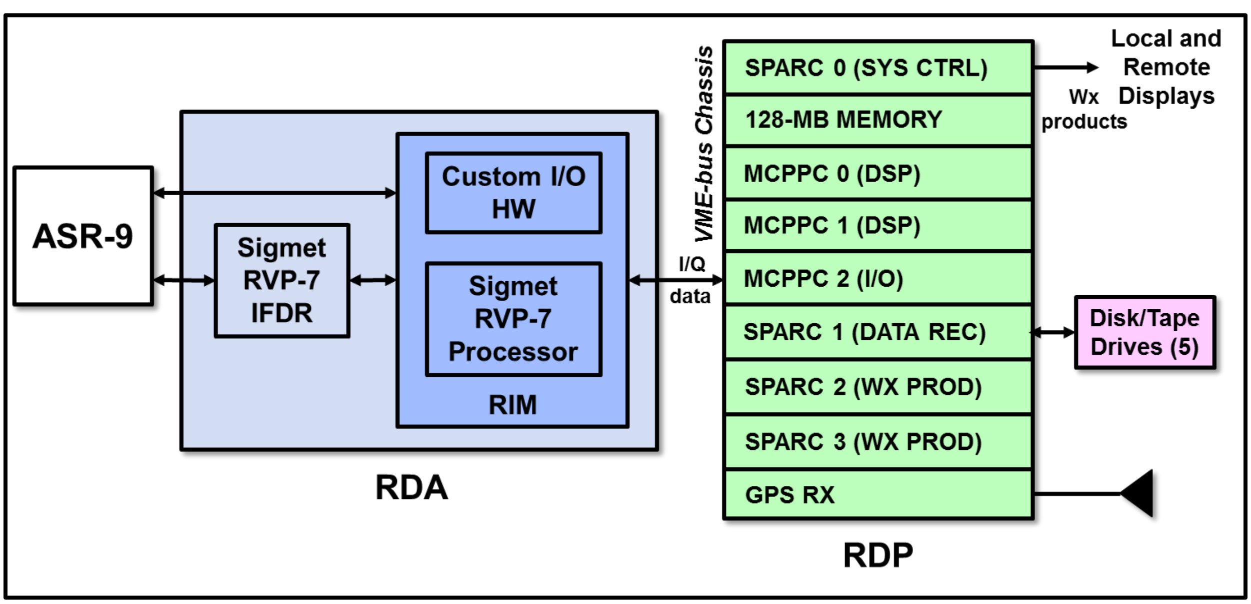

Figure 4. Block diagram of the current WSP.

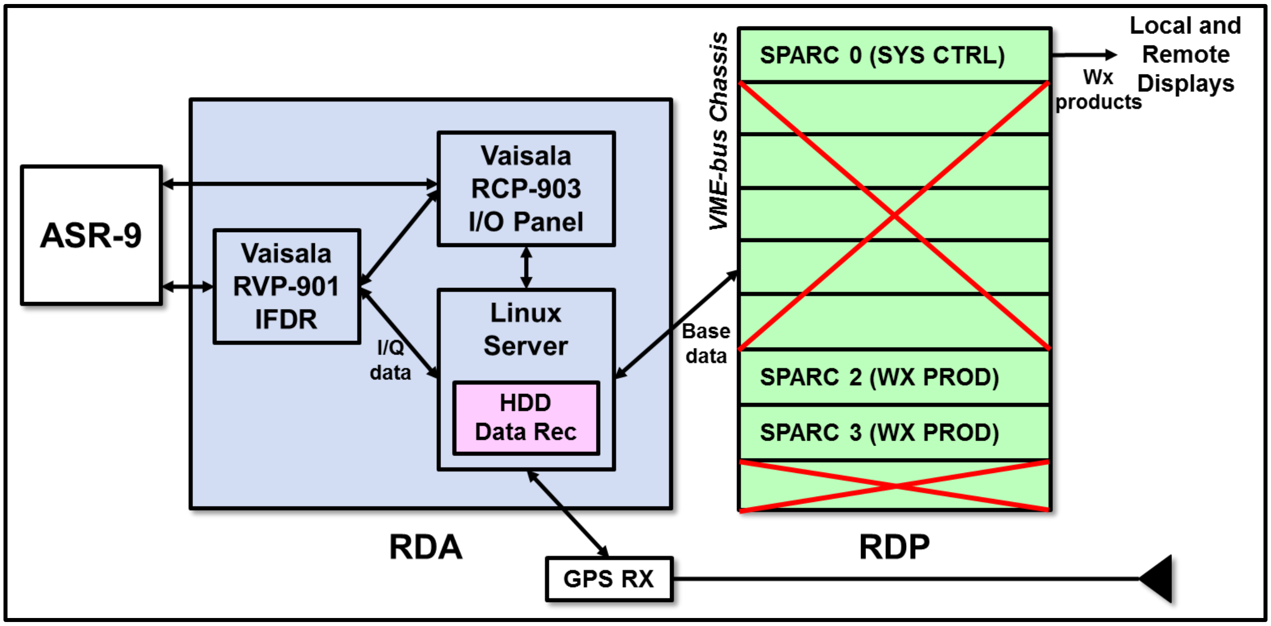

Figure 5. Block diagram of the Phase 1 WSP technology refresh.

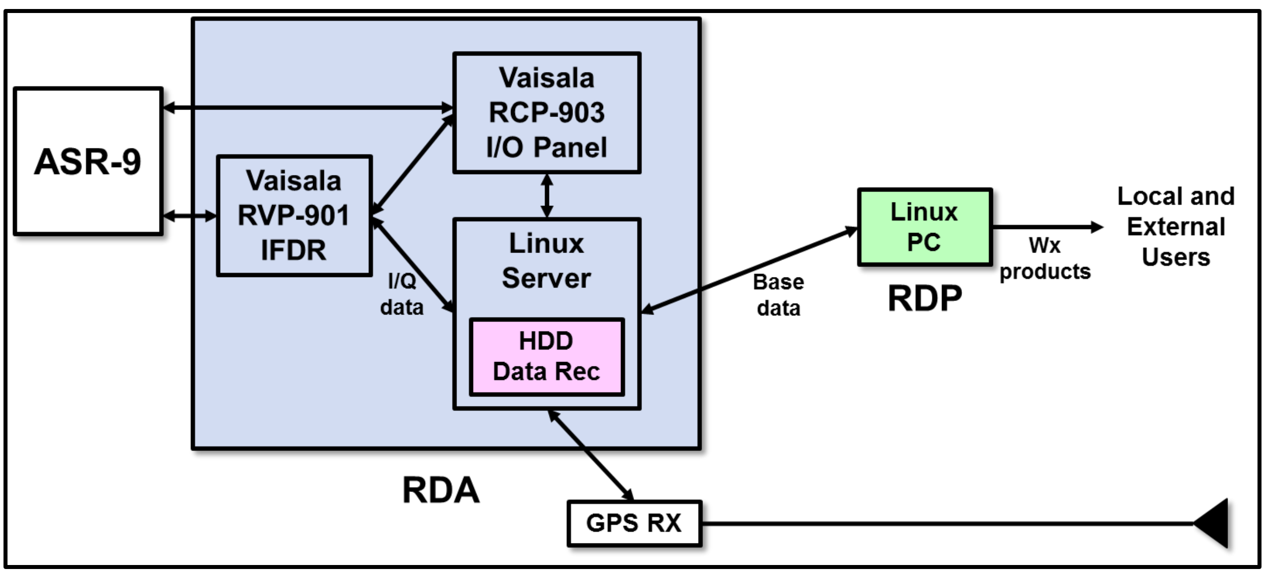

Figure 6. Block diagram of the Phase 2 WSP technology refresh.