1. Introduction and Specifications

SIGMET has a long history of introducing innovative signal processing products to the weather radar community. Each of the products listed below have been placed into service at multiple operational and research sites around the world. Many systems from the early 1980's are still operating in the field today.

Year	Model	Units Sold	Major Technical Milestones
1981	FFT	10	First commercial FFT-based Doppler signal processor for weather radar applications. Featured Simultaneous Doppler and intensity processing.
1985	RVP5	161	First single-board low-cost Doppler signal processor. First commercial application of dual PRF velocity unfolding algorithm.
1986	PP02	12	First high-performance commercial pulse pair processor with 18.75-m bin spacing and 1024 bins.
1992	RVP6	150	First commercial floating-point DSP-chip based processor. First commercial processor to implement selectable pulse pair, FFT or random phase 2nd trip echo filtering.
1996	RVP7	>115	First commercial processor to implement fully digital IF processing for weather radar.

SIGMET's RVP6™ signal processor has become an accepted standard for Doppler weather radar in the world market. As the speed of processor chips and A/D convertors has increased, it is now possible to extend the functions of the weather radar signal processor into the traditional realm of the analog IF receiver. Digital IF receivers for weather radar have been successfully implemented in the research community and have demonstrated many advantages in terms of cost, performance and reliability.

SIGMET's RVP7™ weather radar signal processor combines a digital IF receiver with the proven reliability and performance of the RVP6 signal processing algorithms. The result is a flexible signal processing system that fully integrates the features and advantages of a digital IF receiver. The system operates on wide dynamic range (>90 dB) IF signals so that no LOG receiver is necessary. Phase stability for typical magnetron systems is better than 1 degree. Aside from the performance benefits, the reduction in analog receiver components means substantial cost savings, both in the initial purchase and in reduced maintenance costs over the system's lifetime. Also, the RVP7 is ideal for easy conversion of conventional radars to high performance Doppler systems.

1.1 System Design Concept

A block diagram of the RVP7 is shown in Figure 1–1. The system consists of:

- The IFD IF Digitizer in the radar receiver cabinet.
- The RVP7 Processor itself, consisting of an RVP7/Main board and one or more RVP7/AUX cards that provide additional processing speed and memory.

The two units are connected by a fiber optic downlink cable, and by a coax uplink for timing, control, and AFC output.

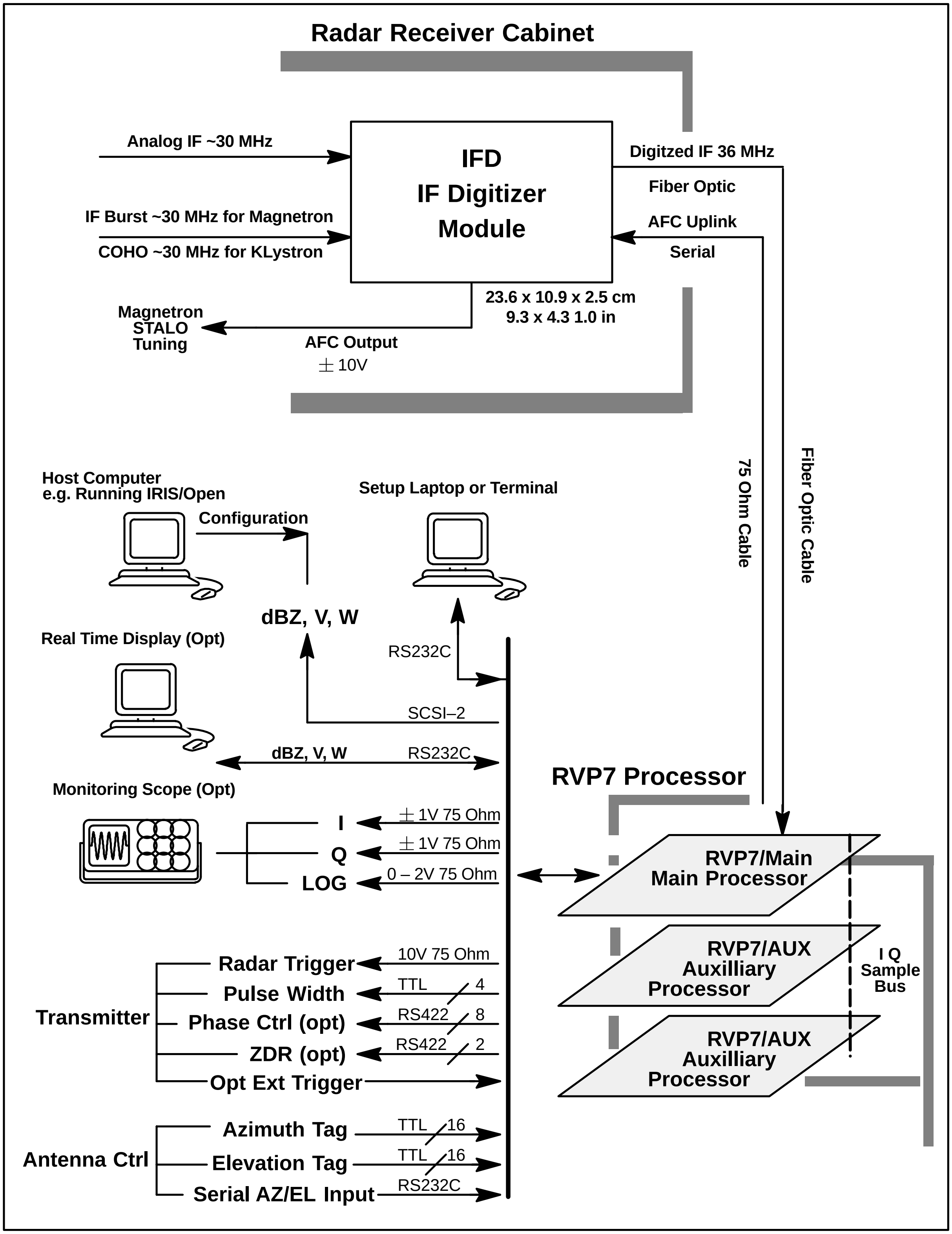
The IFD IF Digitizer is located in the radar receiver cabinet. This is connected to the analog IF at the same point where a traditional LOG receiver would be connected. For magnetron systems the transmit burst pulse sample is also input to the digitizer. In traditional magnetron radars the burst is used for phase locking and for AFC of the STALO. The RVP7 samples the burst pulse and performs these same operations digitally. For Klystron systems, the ~30 MHz COHO is input directly in place of the burst pulse. The output of the IFD™ IF Digitizer is a fiber channel link to the RVP7 Processor, which may be located up to 100 meters away.

The RVP7 Processor receives the digital IF samples from the fiber optic link and performs two stages of processing:

- **Stage 1 Processing: Digital Receiver Functions to Obtain I, Q and Burst Pulse Statistics**
  This processing is performed on the RVP7/Main board and includes filtering and extraction of wide dynamic range "I" and "Q" values. In addition, the burst pulse is analyzed with respect to frequency, phase and amplitude to provide digital phase locking, AFC and advanced processing and control features not available in traditional radars.
- **Stage 2 Processing: Weather Information Extraction to Obtain Intensity, Velocity and Width**
  These operations include Doppler and intensity processing to extract the calibrated reflectivity, the mean velocity and the spectrum width. Clutter filtering by Doppler or statistical techniques, thresholding, and velocity unfolding by dual PRF, and range aliasing filtering/unfolding by the SIGMET Doppler Doubler technique are also performed by the RVP7. This stage of processing uses the same processing algorithms employed in SIGMET's RVP6 processor.

The motivation for the layout is to make the cleanest possible digital capture of the IF signal. This is the highest priority design consideration which requires careful analog design to minimize the presence of digital interference and stray radiation that could add noise to the IF signal. This is accomplished by careful shielding and separation of the A/D convertors from the rest of the digital processing using the fiber optic link. An added benefit is that the signal processor can be located up to 100 meters away from the receiver cabinet.

Figure 1–1: Overall Block Diagram of the RVP7



1.2 RVP7 Digital Receiver Processing Advantages

1.2.1 What is a Digital IF Receiver?

A digital IF receiver accepts the analog IF signal (typically 30 MHz), processes it and outputs a stream of wide dynamic range digital "I" and "Q" values. These quantities are then processed using algorithms similar to those in the SIGMET RVP6 processor. Additionally, the digital receiver can accept the transmit pulse "burst sample" for the purpose of measuring the frequency, phase and power of the transmit pulse. The functions that can be performed by the digital receiver are:

- IF band pass filtering
- "I" and "Q" calculation over wide dynamic range
- Phase measurement and correction of transmitted pulse for magnetron systems – from burst sample
- Amplitude measurement and correction of transmitted pulse – from burst sample
- Frequency measurement for AFC output – from burst sample

The digital approach replaces virtually all of the traditional IF receiver components with flexible software-controlled modules that can be easily adapted to function for a wide variety of radars and operational requirements.

1.2.2 Reduced Initial Cost

The algorithms that are performed digitally can provide the functions that are traditionally provided by the following analog components:

- COHO
- Linear IF amplifier
- Automatic Gain Control (AGC) circuitry
- LOG amplifier
- Quad Phase Detector
- IF Matched Band Pass Filters
- AFC feedback circuit

To achieve the same level of output quality, the cost of these components is greater than the digital receiver approach. For example, a high speed attenuator to implement IAGC alone costs over $5,000 USD.

1.2.3 Reduced Life Cycle Cost

Reduced Cost of Sparing

Over the life of a radar system, components will fail and must be replaced either from spares or from parts ordered from the manufacturer. It is also necessary to perform routine maintenance to make sure that the system is properly tuned.

The digital approach reduces the cost of providing spares for the receiver system. In addition the expansion of digital technology means that the price and availability of analog components may not be favorable over the 20 year life of a radar system.

Reduced Scheduled Maintenance Costs

Another advantage of the digital technology is that the system software includes not only processing algorithms, but tuning algorithms as well. For example, with traditional COHO phase locking, the lock gate must be manually tuned and rechecked periodically by a trained technician to assure that the COHO is locking to the optimal part of the burst pulse. With a digital receiver, the locking algorithm automatically detects the pulse and selects the optimal part of the pulse for performing the phase measurements. This means a more robust system performance without the need for tuning by a skilled technician.

Similarly, the AFC feedback is based on the burst pulse analysis that is performed by the Main Processor Board. This eliminates the need to have a skilled technician periodically check and tune the AFC sampling gate as a function of pulsewidth.

Reduced MTTR and Higher System Availability

In the event of a failure in an analog receiver, there are many components that could potentially be the source of the problem. If a digital receiver fails, there are fewer modules that need to be checked. In the case of the SIGMET design, there are only two LRU's (lowest replaceable unit). In addition, on-board diagnostic software can isolate the faulted LRU in most cases. This increases the system availability by reducing the MTTR. It also means that a technician with minimal skills can make the replacement as compared to the case for the analog components.

1.2.4 Performance and Flexibility Examples

Performance – Wide Dynamic Range "I" and "Q" for Better Clutter Cancelation

Wide dynamic linear range is critical for clutter cancelation. The digital receiver provides wide dynamic range for "I" and "Q" without the need for a LOG receiver and specialized IAGC circuitry that is very sensitive to calibration. Without calibrated IAGC, typical analog components (LIN Amp + Quad Phase Detector) provide a true linear range window of only 30 to 40 dB. SIGMET's digital receiver approach provides a true linear range of 90–100 dB.

Flexibility – Adaptable Algorithms

The processing algorithms in a digital receiver can be adapted for different radar systems and modes of operation. For example, the band pass filters can be matched to the pulsewidth by changing the filter software. In the analog approach, the IF signal must be physically switched between fixed hardware filter modules when the pulsewidth is changed.

Performance – Burst Pulse Analysis

The burst pulse is the sample of the transmitted pulse. The burst pulse analysis is performed by the RVP7/Main Processor on the digitized version of this pulse to obtain the amplitude, frequency and phase of the transmitted pulse. The burst pulse statistics provide an important tool for monitoring and improving the radar performance. For magnetron systems, the burst pulse phase measurement takes the place of analog COHO locking. An example of an optimization that is not performed by most radars is that the transmitted power is measured from the burst pulse to automatically correct for transmit power jitter which effects the stability of the system for clutter cancelation. In addition, if the burst pulse power falls below a selectable threshold, a fault warning is issued.

Performance – Improved Phase Stability at Long Range for Magnetron Systems

For a magnetron system, the low-Q analog COHO which is locked to the transmit pulse is essentially replaced by a high-Q stable oscillator. This reduces the loss of coherency with range that is characteristics of magnetron radars.

Performance – 2nd Trip Echo Filtering and Recover

The digital phase locking and increased range coherency are important for the implementation of advanced processing algorithms such as SIGMET's Doppler Doubler 2nd trip echo filtering. For this algorithm to function well a high degree of radar coherency is required out to ranges of 240 km which is difficult to achieve with an analog locking approach.

1.3 Comparison of Analog vs Digital Radar Receivers

A digital receiver replaces many of the costly and fussy components that are required in an analog receiver. This section compares an IFD digital receiver with the analog components that are typically used in both magnetron and klystron systems.

1.3.1 Magnetron Receiver Example

A typical analog receiver for a magnetron system is shown in the top portion of Figure 1–2. The received IF signal is first applied to one of several bandpass filters that match the width of the transmitted pulse. The filter selection is usually done with relays. The narrow band waveform is then split. Half is applied to a LOG amplifier having a dynamic range of 80–100dB, from which a calibrated measurement of signal strength can be obtained. The LOG amplifier is required because it is almost impossible to build a linear amplifier with the required dynamic range. However, phase distortion within the LOG amplifier renders it unsuitable for making Doppler measurements; hence, a separate linear channel is still required.

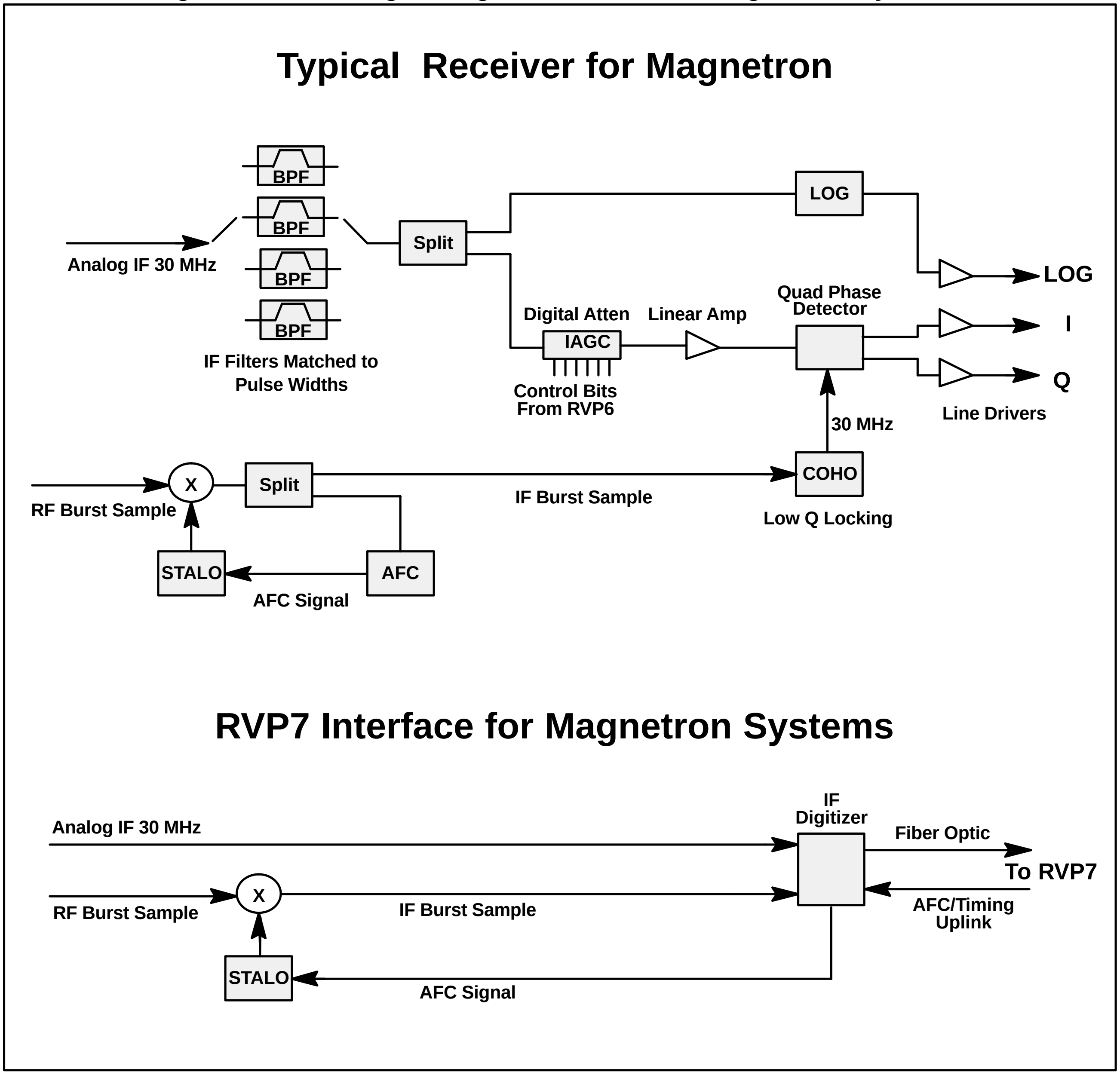
The linear amplifier is fed from the other half of the bandpass filter split. It may be preceded by a gain control circuit (IAGC) which adjusts the instantaneous signal strength to fall within the limited dynamic range of the linear amplifier. The amplitude and phase characteristics of the IAGC attenuator must be calibrated so that the "I" and "Q" samples may be corrected during processing.

The IF output from the linear amplifier is applied to a pair of mixers that produce "I" and "Q". The mixer pair must have very symmetric phase and gain characteristics, and each must be supplied with an accurate 0-degree and 90-degree version of the Coherent Local Oscillator (COHO). The later is usually obtained by sampling a portion of the transmitted pulse, and then phase locking an oscillator that continues to "ring" afterward. Phase locked COHO's of this sort can be very troublesome – they often fail to lock properly, drift with age, and fail to maintain coherence over the full unambiguous range.

The transmit burst that locks the COHO is also used by the Automatic Frequency Control (AFC) loop. The AFC relies on an FM discriminator and low pass filter to produce a correction voltage that maintains a constant difference between the magnetron frequency and the reference STALO frequency. The AFC circuit is often troublesome to set and maintain. Also, since it operates continuously, small phase errors are continually being introduced within each coherent processing interval.

In contrast, the IFD receiver is shown in to lower portion of Figure 1–2. The only old parts that still remain are the microwave STALO oscillator, and the mixer that produces the transmit burst. The burst pulse and the analog IF waveform are cabled directly into the IFD on SMA coax cables. Likewise, the AFC control voltage is also a simple direct connection. These three cables constitute the complete interface to the radar's internal signals; no other connections are required within the receiver cabinet.

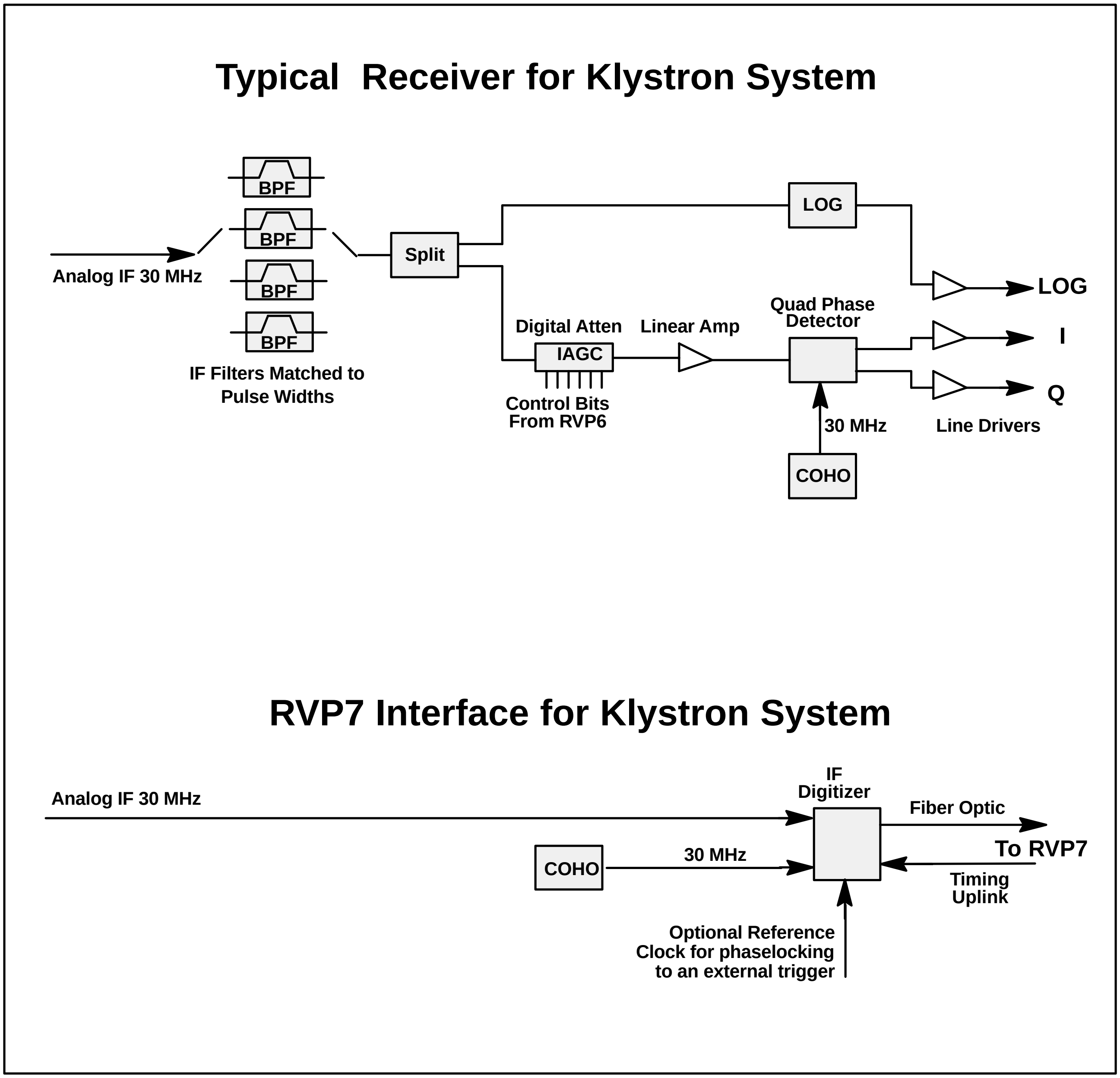
Figure 1–2: Analog vs Digital Receiver for Magnetron Systems



1.3.2 Klystron Receiver Example

A typical analog receiver for a klystron system is shown in the top portion of Figure 1–3. The arrangement of components is almost identical to the magnetron case, except that the COHO operates at a fixed phase and frequency, and there is no AFC feedback. The phase stability of the klystron is thus greatly improved; but the system is still constrained by limited linear dynamic range, IAGC inaccuracy, quad phase detector asymmetries, etc. Again, the IFD eliminates all of these components and results in a very clean and simple receiver system.

Figure 1–3: Analog vs Digital Receiver for Klystron Systems



1.4 Digital IF Front End Processing

The RVP7 design concept is to perform very little signal processing within the digitizer module itself. This is to minimize the presence of digital components that might interfere with the clean capture of the IF signals.

The digitized IF and burst pulse samples are multiplexed onto the fiber channel link which provides the digital data to the RVP7/Main board at approximately 540-MBits/sec. The 14-bit samples are encoded for transmission over a fiber channel link. This optical link allows the IFD to be as far as 100 meters away from the RVP7/Main board and provides an added degree of noise immunity and isolation.

The uplink input from the RVP7/Main board provides the timing for multiplexing the burst pulse sample with the IF signal. In addition, it is used to set the AFC DAC output level, and to perform self tests.

1.4.1 Burst Pulse Analysis for Amplitude/Frequency/Phase

The burst pulse analysis provides the amplitude, frequency and phase of the transmitted pulse. The phase measurement is analogous to the COHO locking that is performed by a traditional magnetron radar. The difference is that the phase is known in the digital technique, so that range dealiasing using the SIGMET Doppler Doubler™ technique is possible. Amplitude measurement (not performed by traditional radars) can provide enhanced performance by allowing the "I" and "Q" values to be corrected for variations in the both the average and the pulse-to-pulse transmitted power. In addition, a warning is issued if the burst pulse amplitude falls below a threshold value.

The burst pulse data stream is first analyzed by an adaptive algorithm to locate the burst pulse power envelope (e.g. 0.8 μsec). The power-weighted phase of the burst pulse and the total burst pulse power is then computed. The power weighted average phase is used to make the digital phase correction. SIGMET has successfully used the digital phase locking technique based on a single phase sample (at base band) to lock magnetron systems to better than 2 degrees of phase stability. The projected phase stability with 29 samples (e.g., 36 MHz samples over 0.8 μsec) available for locking is better than 1-degree. However, unlike a tradition magnetron radar, COHO drift will not degrade this phase stability with range. For Klystron or other fully coherent systems, the RVP7 samples the COHO and digitally locks to it.

The burst pulse frequency is also analyzed to calculate the frequency error from the nominal IF frequency. The error is filtered with a selectable time constant which is typically set to several minutes to compensate for slow drift of the magnetron. The digital frequency error is sent via the uplink to the IFD in the receiver cabinet where a DAC converts it into an analog output to the magnetron STALO. Klystron systems do not require the AFC.

1.4.2 Main Board IF Signal Processing

The RVP7/Main board performs the Stage 1 processing on the IF digital data stream and outputs "I" and "Q" data values on an internal data bus. In addition, the frequency, phase and amplitude of the burst pulse is measured. The functions performed by the processor are:

- Reception of the digital serial fiber optic data stream.
- Band pass filtering of the IF signal using configurable digital FIR filter matched to the pulsewidth.
- Range gating and coherent averaging (essentially performed during the band pass filtering step).
- Computation of "I" and "Q" quadrature values.
- Adaptive isolation of burst pulse.
- Burst pulse monitoring and statistics.
- Phase correction (for magnetron systems)
- Amplitude correction
- Frequency error calculation for output to AFC DAC.

The advantage of the digital approach is that the software algorithms for these functions can be easily changed. The basic algorithms are stored in ROM on the RVP7/Main Processor Board, with configuration information (e.g., pulsewidth, gate spacing) supplied from the host computer.

The RVP7/Main places the wide dynamic range "I" and "Q" samples directly on a high-speed data bus. The DSP chips on the RVP7/AUX then read the bus to obtain the "I" and "Q" samples that are required for their assigned range bins. These values are used directly for power measurement. No LOG receiver is necessary. Calibration is performed in a manner identical to the analog approach.

The digital matched filter that computes "I" and "Q" is designed in an interactive manner using a TTY and oscilloscope for graphical display. The filter's passband width and impulse response length are chosen by the user, and the RVP7 constructs the filter coefficients using built-in design software. The frequency response of the filter is displayed on a scope, and can be compared with the frequency content of the actual transmitted pulse.

1.5 RVP7 Weather Signal Processing

The processing of weather signals by the RVP7 is based on the identical algorithms and software source code as for the SIGMET RVP6 processor, except that intensity is derived from the wide dynamic range "I" and "Q" values rather than from a LOG receiver. Applications for the RVP7 include:

- Quantitative Rainfall Measurement
- Vertical Wind Profiling
- ZDR Hail Detection
- Tornado Detection and Microburst Detection
- Gust Front Detection
- Dual Channel (Co- and Cross-) Polarization Diversity Measurements
- Airborne Wind Shear Detection
- Target Detection and Tracking
- General Weather Monitoring

The RVP7 has an extensive set of configurable parameters so that costly reprogramming is not required for most operational scenarios. There are three basic processing modes,

- Pulse Pair Mode
- FFT Mode
- Optional Random Phase Mode (Doppler Doubler) for 2nd trip echo filtering.

These modes share some common features that are described first, followed by descriptions of the unique features of each mode.

1.5.1 General Processing features

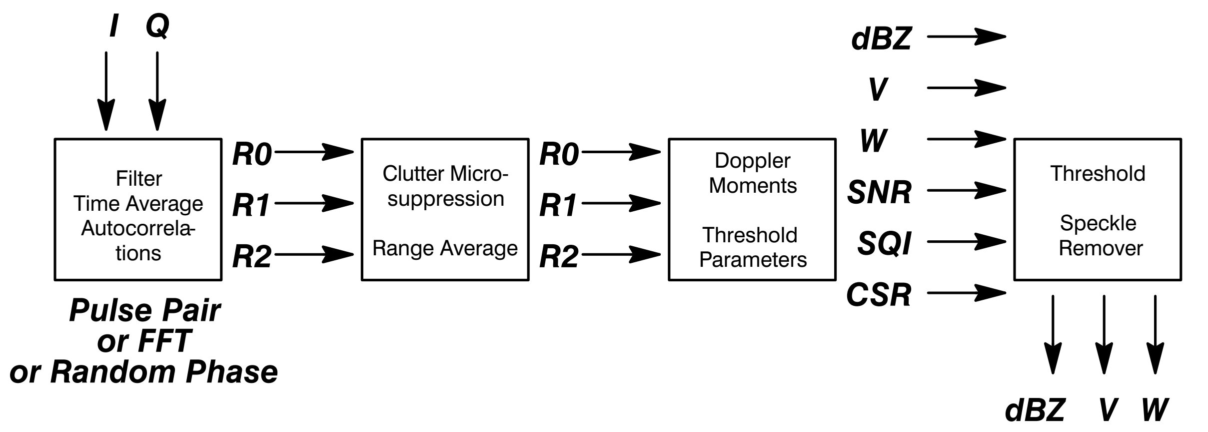
Figure 1–4 shows a block diagram of the processing steps. These are discussed below.

Autocorrelations

The autocorrelations R0, R1 and R2 are produced by all three processing modes. However, the way that they are produced is different for the three modes, particularly with regard to the filtering that is performed.

- Pulse Pair Mode– Filtering for clutter is performed in the time domain. Autocorrelations are computed in the time domain.
- FFT Mode– Filtering for clutter is performed in the frequency domain by an adaptive algorithm. Autocorrelations are computed from the inverse transform.
- Random Phase– Filtering for clutter and second trip echo is performed in the frequency domain by adaptive algorithms. Autocorrelations are computed from the inverse transform.

Figure 1–4: RVP7 Weather Processing Steps



The use of the R2 lag provides improved estimation of signal-to-noise ratio and spectrum width. **Processors that do not use R2 cannot effectively measure the SNR and spectrum width.**

Time (azimuth) Averaging

The autocorrelations are based on input "I" and "Q" values over a selectable number of pulses between 8, 9, 10, ...,256 (255 for FFT and random phase). Any integer number of pulses in this interval may be used. For FFT, if other than a power of two is selected, then the processing is performed on the first N and last N pulses, where N is the nearest power of 2, and the resulting spectra are averaged together. For example, if 50 pulses are selected, then the FFT on the first 32 pulses is averaged with the FFT on the last 32 pulses. The random phase works in a similar manner.

Angle synchronization using the input AZ and EL tag lines can be used to assure that all possible pulses are used during averaging for each, say, 1 degree interval. This minimizes the number of 'wasted' pulses for maximum sensitivity.

TAG Angle Samples of Azimuth and Elevation

During data acquisition and processing it is usually necessary to associate each output ray with an antenna position. To make this task simpler the RVP7 samples 32 digital input "TAG" lines, once at the beginning and once at the end of each data acquisition period. These samples are output in a four-word header of each processed ray. When connected to antenna azimuth and elevation, the TAG samples provide starting and ending angles for the ray, from which the midpoint could easily be deduced. Since the bits are merely passed on to the user, any angle coding scheme may be used. The processor also supports an angle synchronization mode, in which data rays are automatically aligned with a user-defined table of positions. For that application, angles may be input either in binary or BCD.

Range Averaging and Clutter Microsuppression

To improve the accuracy of the reflectivity measurements, the RVP7 can perform range averaging. When this is done, autocorrelations from consecutive range bins are averaged, and the result is treated as if it were a single bin. This type of averaging is useful to lower the number of range bins that the host computer must process.

Range averaging of the autocorrelations may be performed over 2, 3, 4, ..., 16 bins. Prior to range averaging, any bins that exceed the selectable clutter-to-signal threshold are discarded. This prevents isolated strong clutter targets from corrupting the range average, which improves the sub-clutter visibility.

Moment Extraction

The autocorrelations serve as the basis for the Doppler moment calculations,

- Mean velocity – from Arg [R1]
- Spectrum width – from |R1| and |R2| assuming Gaussian spectrum
- dBZ – from R0 with correction for system noise and gaseous attenuation. Uses calibration information supplied by host computer.

These are the standard parameters that are output to the host computer on the SCSI-2 high-speed interface. In addition, these parameters can be output on a serial interface at speeds up to 76.8 K bits per second for local real time display.

The RVP7 also performs a statistical linearization of the power estimate of signals that exceed the +6dBm input saturation level. This gives an additional 4–6dB of headroom to the overall dynamic range.

Thresholding

The RVP7 calculates several parameters that are used to threshold (discard) bins with weak or corrupted signals. The thresholding parameters are:

- Signal quality index (SQI=|R1|/R0)
- Signal-to-noise ratio (SNR)
- Clutter-to-signal ratio (CSR)

These parameters are computed for each range bin and can be applied in AND/OR logical expressions independently for dBZ, V and W.

Speckle Filter

The speckle filter can be selected to remove isolated single bins of either velocity/width or intensity. This feature eliminates single pixel speckles which allows the thresholds to be reduced for greater sensitivity with fewer false alarms (speckles).

Velocity Unfolding

A special feature of the RVP7 processor is its ability to "unfold" mean velocity measurements based on a dual PRF algorithm. In this technique two different radar PRF's are used for alternate N-pulse processing intervals. The internal trigger generator automatically produces the correct dual-PRF trigger, but an external trigger can also be applied. In the later case, the ENDRAY_ output line provides the indication of when to switch rates. The RVP7 measures the PRF to determine which rate (high or low) was present on a given processing interval, and then unfolds based on either a 2:3, 3:4 or 4:5 frequency ratio. Table 1–1 gives typical unambiguous velocity intervals for a variety of radar wavelengths and PRF's.

Table 1–1: Examples of Dual PRF Velocity Unfolding

			Unambiguous Velocity (m/s) for Various Radar Wavelengths			
PRF1	**PRF2**	**Unambiguous Range (km)**	**3 cm**	**5 cm**	**10 cm**	
500	*	300	3.75	6.25	12.50	No Unfolding
1000	*	150	7.50	12.50	25.00	
2000	*	75	15.00	25.00	50.00	
500	333	300	7.50	12.50	25.00	Two Times Unfolding
1000	667	150	15.00	25.00	50.00	
2000	1333	75	30.00	50.00	100.00	
500	375	300	11.25	18.75	37.50	Three Times Unfolding
1000	750	150	22.50	37.50	75.00	
2000	1500	75	45.00	75.00	150.00	
500	400	300	15.00	25.00	50.00	Four Times Unfolding
1000	800	150	30.00	15.00	100.00	
2000	1600	75	60.00	100.00	200.00	

1.5.2 RVP7 Pulse Pair Processing

Prior to pulse pair processing, the input "I" and "Q" values are filtered for clutter using a 4th order Chebyshev IIR filter. Either 40 or 50 dB filters can be provided in various widths. Up to 2048 bins can be processed. Lags R0, R1 and R2 are computed by time domain techniques. The use of the R2 lag allows proper calculation of the SNR and spectrum width under the assumption of a Gaussian weather spectrum + white noise. The final R0, R1 and R2 lags are then output to the range averaging step and moment extraction.

1.5.3 RVP7 FFT Processing

For FFT processing the input "I" and "Q" values are double buffered to allow simultaneous data acquisition and processing. The FFT approach allows clutter cancelation to be performed in the frequency domain. A dual FFT approach with spectrum averaging is used to match the number of samples to the transform size. For example, to process 50 samples, the FFT of the first 32 samples is averaged with the FFT of the last 32 samples to obtain the power spectrum estimate for the 50 samples. This means that the sample size is not constrained to be a power of two, which provides flexibility in matching the scan rate to the azimuth averaging. The maximum FFT sample size is 128 samples which would allow as many as 255 pulses to be averaged.

Three standard windows are supported to provide the best match of window width to the spectrum dynamic range:

- Rectangular
- Hamming
- Blackman

An RVP7 with a single RVP7/AUX board will do FFT processing in up to 2048 bins.

After the FFT step, clutter cancelation is done using a selectable fixed width filter that interpolates across the noise or any overlapped weather. This technique preserves overlapped weather as compared to IIR or FIR time domain filter which will always attenuate overlapped weather to some extent, depending on the spectrum width. After clutter cancelation, R0, R1 and R2 are computed by inverse transform and these are used for moment estimation.

1.5.4 Doppler Doubler – Random Phase Processing

Second trip echoes can be a serious problem for applications that require operation at a high PRF. Second trip echoes can appear separately or can be overlaid on first trip echoes (second trip obscuration). The random phase technique separates the first and second trip echoes so that:

- In nearly all cases, the 2nd trip echo can be removed from the first trip even in the case of overlapped 1st and 2nd trip echoes. The benefit is a clean first trip display.
- The 2nd trip echoes can be recovered and placed at their proper range at 1st trip/2nd trip signal ratios of up to 40 dB difference for overlapped echoes. Because of the wide dynamic range of weather echoes, this power limit will sometimes be exceeded.

The technique requires that the phase of each pulse be random. Digital phase correction is then applied in the processor for the first and second trips. The critical step is the adaptive filter which removes the echo of the other trip to increase the SNR. Magnetrons have a naturally random phase. For Klystron radars, a digitally controlled precision IF phase shifter is required. The RVP7 provides an 8-bit RS422 output for the phase shifter.

For more information on the technique refer to Joe, et.al., 1995.

1.5.5 Output Data

The RVP7 output data consist of Velocity, Spectrum Width, Corrected Reflectivity, Uncorrected Reflectivity, and Differential Reflectivity. Each of these parameters occupies eight bits, and they are provided in either or both of two formats:

- Archive Format, in which four bytes are packed in two 16-bit words. The archive format offers the densest packing and is intended for applications which record data on tape or disk.
- Display Format, in which the values are individually available in the low byte of each output word. The Display format offers the simplest access to any particular parameter and is useful when the data are being sent to a color display unit.

1.6 RVP7 Control and Maintenance Features

1.6.1 Radar Control Options

The RVP7 also performs several important radar control functions:

- Trigger generation — up to 6 programmable triggers.
- Pulsewidth control (four states controlled by four bits).
- Angle/data synchronization — to collect data at precise azimuth intervals (e.g., every 0.5, 1, 1.5 degrees) based on the AZ/EL angle inputs.
- Phase shifter — to control the phase on Klystron systems.
- ZDR switch control — for horizontal/vertical or other polarization switching scheme.
- AFC output based on the burst pulse analysis for magnetron systems.

Pulsewidth and trigger control are both built into the RVP7. Four TTL output lines can be programmed to drive external relays that control the transmitter pulsewidth. The internal trigger generator drives six separate lines, each of which can be programmed to produce a desired waveform. The trigger generator is unique in that the waveforms are stored in RAM and can be modified interactively by user software. Thus, precisely delayed and jitter-free strobes and gates can easily be produced. For each pulsewidth there is a corresponding maximum trigger rate that can be generated. Note, however, that the RVP7 can also operate from an external user-supplied trigger. In either case, the processor measures the trigger period between pulses so that user software can monitor it as needed.

The RVP7 also supports trigger blanking. Any combination of the six output triggers can be blanked in response to the input signal at TAG Bit #0. The polarity of the input signal is selectable. When trigger blanking is enabled, the On/Off state of the trigger during each ray is encoded into the header information for that ray.

Traditionally SIGMET signal processors have also incorporated digital and analog gain control features, but these are not required in the case of the digital receiver.

1.6.2 Local TTY and Scope Setups

The RVP7 stores an extensive set of configuration information in nonvolatile RAM. The purpose of these data is to define the exact configuration of the RVP7 upon startup. The setup information can be accessed and modified using either a serial TTY or the host computer. This setup procedure becomes even more interactive when an ordinary oscilloscope is attached to the RVP7's "Q" output signal. The processor can then produce graphical displays using a unique self triggering multistroke synthesized waveform. These displays make it very simple to find and align the transmitted burst, analyze its frequency content, design an appropriate matched filter, and analyze the resulting receiver waveforms.

1.6.3 Built-In Diagnostics

On power-up, the RVP7 performs a sequence of internal self-tests. The test sequence requires about four seconds to perform, and tests approximately 95% of the internal digital circuitry. Errors are isolated to specific sections of the board as much as possible. If any check fails, the user can be certain that some component is not functioning correctly. However, there is a very small chance that even a defective board may pass all the tests; the failure may be in one of the few areas that can not be checked. The RVP7/Main board blinks its LEDs three times on power-up, and then leaves Grn:*On* and Red:*Off* unless a failure is detected. In this way, there is immediate visual confirmation of the diagnostic tests, even if the host computer has not yet been connected. Likewise, the IFD LEDs also blink on power-up, and then both remain *On* to indicate success (See Section 2.1.8).

1.7 Support Software

The SIGMET IRIS system provides a complete set of tools for the calibration, alignment and configuration of the RVP7. These include:

- **IRIS Radar Utilities Software Package –** provides utilities for calibration and alignment of the signal processor. Display of all signal processor outputs vs range or at a single bin is via the **ascope** utility. This utility also includes an I/Q signal simulator for testing and development of processing strategies.
- **IRIS/Radar Software Package –** provides fully automated scanning and control of a radar system with local product generation and display. Remote control/monitoring and network communication are standard.
- **IRIS/Analysis Software Package –** implements most of the NEXRAD and TDWR algorithms for general weather monitoring and wind shear detection. Includes automatic tracking, automatic warning and comprehensive displays of weather radar information.

1.8 RVP7 Technical Specifications

1.8.1 IFD Digitizer Module

Signal Inputs	IF received signal, 50Ω, +6 dBm max (See note in 1.8.2 below). Magnetron burst sample, 50Ω, +6 dBm max.
IF Signal Level	An internal out-of-band noise generator eliminates the need to supply a minimum dither power via the IF input. This makes it very simple to drive the IFD inputs.
IF Signal Bandwidth	As wide as possible to prevent distortion within the passband. 23–37MHz recommended for a 30MHz IF system.
Intermediate Freq.	22–32MHz, 40–50MHz, 58–68MHz.
A/D Conversion	Resolution: 14-bits. Sampling rate: 35.9751 MHz (custom rates from 33.5 to 39.5MHz). Sampling jitter: less than 2.5ps.
Anti-alias Filter	5-pole elliptic, 23–37MHz passband, 0.5dB ripple from 26–34MHz, 2dB insertion loss, externally mounted. This is optimized for an IF of 30MHz. Other specs are available by special order.
AFC-Out / ClkRef-In	This is a dual-function SMA connector. • For a magnetron system this is an output voltage in the range –10V to +10V. It is intended to close the AFC feedback loop by driving the STALO's frequency control • For a Klystron system (or any synchronous system) this is an optional input that can be driven by an external reference clock. The purpose is to provide phase locking when the RVP7 is used with an external trigger. Input is 2–60MHz at –10 to 0dBm.
Fiber Downlink	Class I laser transmitter, 850nm, –1dBm 540MHz optical link, 62.5/125-micron multimode ST cable.
Coax Uplink	75Ω, electrically isolated (33KΩ) from receiver's ground.
Fiber/Coax Length	Up to 100-meters each, 15-meters standard.

1.8.2 Digital "I" and "Q" Synthesis

FIR Filter	Digital FIR bandpass filter matched to pulsewidth. Filter coefficients are derived using built-in design software and an interactive graphical procedure.
Impulse Response	Up to 2.92 μsec at 125-meter resolution for Rev.A board. Up to 6.25 μsec at 125-meter resolution for Rev.B board.
IF Dynamic Range	98dB at 1MHz Matched Filter bandwidth. Note: An additional 6dB of calibrated linear headroom is provided via statistical linearization of partially saturated FIR (I,Q) outputs. This extends the usable IF input power level from +6 dBm to +12 dBm.

Range Resolution	50.0, 58.3, 66.7, 75.0, 83.3, 91.7, 100.0, 108.3, 116.7, 125.0, and 133.3 meters between bins.
Maximum Range	5460 times the range resolution, e.g., 682km at 125-meter resolution, 409km at 75-meter resolution. Note that these numbers are halved for dual-receiver operation.
Number of Ranges	Up to 2048 bins, positioned at arbitrary integer multiples of the range resolution via a bit mask.
Phase Stability	Klystron: Better than 0.2 degrees. Magnetron: Better than 0.8 degrees (for a 0.8 μsec pulse).
Amplitude Correction	Within 0.1dB, pulse-to-pulse.

1.8.3 Computed Weather Parameters

Operating Modes	Pulse Pair, FFT, and Doppler Doubler (Random phase 2nd trip filtering/recovery).	
Pulses / Ray	Continuously adjustable from one to 256 pulses for pulse pair, 8 to 255 for FFT. Doppler data are not available at 1 pulse/ray.	
Range Normalization	Inverse square range correction optionally applied to all reflectivity measurements. Can include linear term for gaseous attenuation. Custom range normalization can be loaded by the user.	
Velocity Unfolding	Dual-PRF technique using either 2:3, 3:4 or 4:5 frequency ratio. The RVP7 performs all of the unfolding steps.	
dBZ	Calibrated equivalent radar reflectivity	8 or 16 bits
V	Mean radial velocity	8 or 16 bits
W	Spectrum width	8 or 16 bits
I & Q	Time series	16 bit samples
FFT	Doppler Spectrum output in FFT mode	16 bit powers

1.8.4 Processing Speed and RVP7/AUX Option

RVP7/Main Board	The main board has a an average computational throughput of 90 MegaFlops (32-bit floating point operations per second). This is 2.25 times the speed of a single RVP6 main board, and 0.64 times the speed of a 2-board RVP6 system.
RVP7/AUX Board	Additional processing throughput is available by adding one or two RVP7/AUX boards to a single RVP7/Main board. Each AUX board adds 10 DSP chips to the system. The boards communicate with each other via 8-bit links on the backplane.

Speedup over single RVP7 board

1 AUX board:	x4.3 (equivalent to a 4-board RVP6 system)
2 AUX boards:	x7.7

1.8.5 Clutter Filters

Doppler Filter	For pulse pair processing, 4th order Chebyshev Infinite Impulse Response (IIR) digital high pass filters for "I" and "Q" Doppler signals. 40dB and 50 dB stopband attenuation in seven different widths. For FFT processing, frequency domain interpolating clutter filter. Interpolation width is selectable in terms of number of interior spectral components. Up to 60 dB cancelation can be achieved with Blackman window weighting function.
Filter Placement	A different filter may be selected for each range bin. This permits more "aggressive" filters to be used at closer ranges, where ground clutter presents more of a problem.

1.8.6 Data Thresholds

Concept	Each computed parameter must pass several data quality checks before being considered valid. Non-zero output values represent valid measurements; zero values stand for rejected data. All thresholds are user-programmable.
Intensity Check	Integrated receiver power must exceed the noise level by a minimum amount. Failure to pass invalidates both corrected and uncorrected reflectivity outputs.
Signal Quality Index	SQI is the ratio of first lag to zeroth lag Doppler autocorrelation. SQI must exceed a prescribed level for reliable Doppler measurements. Failure to pass invalidates velocity, width, and corrected reflectivity outputs.
Clutter Power Check	When clutter power exceeds a maximum level the IIR filter is unlikely to perform fully. Failure to pass invalidates velocity, width, and corrected reflectivity outputs.
SNR Check	The algorithm for computing width is unbiased only for large SNR. Corrected intensity data are used to estimate the SNR and accept or reject the computed widths.
Speckle Remover	Isolated valid data bins that have invalid bins on both sides can optionally be rejected. Such bins are likely not to correspond to real weather targets.

1.8.7 Other Data Outputs and Features

Time Series	Direct samples of the high 8-bits of I, Q, and LOG receiver inputs. Optional floating-point format gives 12 bits of precision across a 190dB range.
FFT	Spectrum components in 0.01 dB resolution.
Synchronized Rays	The RVP7 can adjust the starting time of each ray so that rays always begin when the antenna is on or near one of a set of user-defined

	positions. In this application, antenna angles are wired to the TAG input lines.
Measured PRF	Average trigger period is measured and can be read by the user.
Diagnostics	The RVP7 microcode performs self-tests on approximately 95% of all internal digital circuitry. Failures are pinpointed to individual circuit areas whenever possible.
I/O Tests	Special opcodes are provided to test the host computer interface.
Setup TTY	A local TTY may be plugged into the RVP7 to configure the board's power-up settings. Many internal processing and operational settings can also be chosen with the local TTY. These functions can also be accessed via the host computer's interface using "chat" mode.
Live Data Monitor	A selectable data stream my be printed to the Setup TTY's output port during normal RVP7 operation. This allows various internal parameters to be continuously monitored while weather data are being processed.

1.8.8 Real Time Display Serial Stream

Concept	The serial stream is generated by "evesdropping" on the data that are being processed for the host computer. Up to four data parameters may be monitored, either as 8-bit bytes or as packed 4-bit nibbles. The data may be sampled from any range interval. The operation of the Real Time Display is transparent to the host computer, and the display may be switched on and off without causing interference.
Baud Rate	300 to 76800 Baud.

1.8.9 External Trigger Input

Capabilities	The RVP7 can lock to an external pretrigger supplied by the user. Either the rising or the falling input edge can serve as the pretrigger point.
Pretrigger Time	Variable, up to 200 μsec.
Synchronization	Data acquisition circuitry can lock to external trigger with less than 0.014 μsec jitter from pulse to pulse.
PRF Range	50Hz Minimum; 6KHz Maximum.

1.8.10 Internal Trigger Generator

Design	Six trigger lines are driven from a user-supplied waveform table. Any trigger waveform may be configured having 0.028 μsec resolution and spanning 200 μsec around radar zero range.
PRF Range	50Hz to 20KHz with 0.02% accuracy.
PRF Protection	For each pulsewidth, the RVP7 maintains a corresponding user-defined maximum PRF. Trigger rate will never exceed this bound.

Output Level	TTL, or 0–15V (open circuit) into a load impedance of 50–75Ω.

1.8.11 Host Computer Interface

SCSI	Direct connection to single ended SCSI-I or SCSI-2 bus on a 50-pin Centronics connector.
Byte Swapping	The RVP7 uses 16-bit words as its fundamental data type. The two 8-bit bytes within each word may be swapped during I/O, thereby making it easy to interface to computers that use either convention.

1.8.12 Radar Control Signals

Pulsewidth	Four TTL outputs may be wired to the radar's pulsewidth control lines. Any encoding scheme may be used on the four wires.
Phase Control/DAFC	8-bits,TTL or RS422, programmable drivers for modulation of the transmit phase. Note that these lines can also function as Digital AFC control outputs.
Polarization Control	2-bits, TTL or RS422, controlling up to four polarization states.
Uncommitted Inputs	32 digital TAG inputs are sampled at the beginning and end of each ray, and are output with the processed data.
Coax Drivers	Three uncommitted coax cable drivers are provided. They can produce a 7 volt signal into 75Ω. Their inputs may be connected to any RVP7 TTL signal that the user wishes to drive over a length of coax.
I / Q / LOG Outputs	These outputs are unavailable, pending driver software. The "Q" output is used for local oscilloscope plotting, however.

1.8.13 Physical and Environmental

Packaging	3-slot chassis typically configured with RVP7/Main board and RVP7/AUX. Spare slot can accommodate a second RVP7/AUX board for *extremely* high performance applications.
RVP7 Chassis	432 wide x 495 long x 134 mm high 17 wide x 19.5 long x 5.25" high
IFD Receiver	30 wide x 109 long x 236 mm high 1.2" wide x 4.3 long x 9.3" high
IFD Options	Add 33 mm (1.3") width for attached power supply Add 20 mm (0.8") width for attached antialias filter
Input Power	100–240 VAC 47–63 Hz auto-ranging for RVP7 and IFD
RVP7/Main Power	Main chassis requires 70 Watts of input power with one RVP7/AUX board installed.
IFD Power	Digitizer is conduction cooled and requires 9 Watts of input power when used with the attached power supply. The power supply requirements are slightly different for each version:

Rev.C (12-Bit): This unit requires +12V @ 60ma, –12V @ 60ma, and +5V @ 1.1A. All three voltages must be present at all times for normal operation, and the ±12V supplies can not be increased to ±15V.

Rev.D (14-Bit): This unit requires +(12–15)V @ 60ma, –(12–15)V @ 60ma, and +5V @ 1.0A. The +5V must always be present, but the other two are only required if the analog AFC output signal is being used. Moreover, those two supplies can be either ±12V or ±15V.

Note: These individual current and voltage requirements are subject to change when new versions of the IFD are introduced. To insure simple future upgrades, it is recommended that the IFD be powered by its attached power supply.

RVP7 Chassis EMI	The chassis uses integral shielding and line filters designed to limit emissions and susceptibility to interference from other devices. The +5 volt power supply is designed to meet FCC and VDE "Class B", the +/–15V power supply is compliant with FCC "Class A".	
Environmental	Temperature	0C (32F) to 50C (122F)
	Humidity	0 to 95% non-condensing
Reliability	MTBF>50,000 hours (based on actual RVP6 field data).	
Safety	Designed to meet UL 1950 & IEC 950, Components are UL, CSA & VDE compliant.	