4 Operation and Performance

This chapter describes the satellite acquisition and tracking processes, performance characteristics and system architecture. This discussion assumes that you are familiar with the basic theory of the Global Positioning System. Before proceeding to the detailed discussion of the satellite acquisition and tracking process, please review the GPS satellite message description on the next page.

The satellite acquisition and tracking algorithms can achieve a position solution without any initialization. The receiver automatically selects and tracks the best combination of satellites to compute position and velocity. As satellites move out of view, the SVeeEight Plus GPS receiver automatically acquires new satellites and includes them in the solution set as required.

4.1 GPS Satellite Message

Every GPS satellite transmits the Coarse/Acquisition (C/A) code and satellite data modulated onto the L1 carrier frequency (1575.42 MHz). The satellite data transmitted by each satellite includes a satellite almanac for the entire GPS system, its own satellite ephemeris and its own clock correction.

The satellite data is transmitted in 30-second frames. Each frame contains the clock correction and ephemeris for that specific satellite, and two pages of the 50-page GPS system almanac. The almanac is repeated every 12.5 minutes. The ephemeris is repeated every 30 seconds.

The system almanac contains information about each of the satellites in the constellation, ionospheric data, and special system messages. The GPS system almanac is updated weekly and is typically valid for months. The ephemeris contains detailed orbital information for a specific satellite. Ephemeris data changes hourly, but is valid for up to four hours. The GPS control segment updates the system almanac weekly and the ephemeris hourly through three ground-based control stations. During normal operation, the SVeeEight Plus GPS receiver updates its ephemeris and almanac as needed.

The performance of a GPS receiver at power-on is determined largely by the availability and accuracy of the satellite ephemeris data and the availability of a GPS system almanac.

4.2 Satellite Acquisition and Time to First Fix

4.2.1 Cold-Start

The term cold-start describes the performance of a GPS receiver at power-on when no navigation data is available. Cold signifies that the receiver does not have a current almanac, satellite ephemeris, initial position, or time. The cold-start search algorithm applies to a SVeeEight Plus GPS receiver which has no memory of its previous session (is powered on without the memory backup circuit connected to a source of DC power). This is the default condition of the GPS receiver as received from the factory.

In a cold-start condition the receiver automatically selects a set of eight satellites and dedicates an individual tracking channel to each satellite, to search the Doppler range frequency for each satellite in the set. If none of the eight selected satellites is acquired after a pre-determined period of time (time-out), the receiver selects a new search set of eight satellites and repeats the process, until the first satellite is acquired. As satellites are acquired, the receiver automatically collects ephemeris and almanac data. The SVeeEight Plus GPS receiver uses the knowledge gained from acquiring a specific satellite to eliminate other satellites, those below the horizon, from the search set. This strategy speeds the acquisition of additional satellites required to achieve the first position fix.

The cold-start search sets are established to make syre that at least three satellites are acquired within the first two time-out periods. As soon as three satellites are found, the receiver computes an initial position fix. The typical time to first fix is less than 2 minutes.

A complete system almanac is not required to achieve a first position fix. However, the availability and accuracy of the satellite ephemeris data and the availability of a GPS almanac can substantially shorten the time to first fix.

4.2.2 Warm Start

In a warm start condition, the receiver has been powered down for at least one hour but has a current almanac and an initial position and time stored in memory.

When connected to an external backup battery and power is applied, the SVeeEight Plus GPS receiver retains the almanac, approximate position, and time to aid in satellite acquisition and reduce the time to first fix. When an external back-up battery is not used, the TSIP protocol allows the almanac, an initial position, and time to be uploaded to the receiver via the serial port, to initiate a warm start.

During a warm start, the SVeeEight Plus GPS receiver identifies the satellites which are expected to be in view, given the system almanac, the initial position and the approximate time. The receiver calculates the elevation and expected Doppler shift for each satellite in this expected set and directs the eight tracking channels in a parallel search for these satellites.

The warm start time to first fix, when the receiver has been powered down for more than 60 minutes (the ephemeris data is old), is usually less than 45 seconds.

4.2.3 Garage Search Strategy

During a warm start search, the SVeeEight Plus GPS receiver knows which satellites to search for, based on the system almanac, the initial position (last known position) and the current time. In some cases, the receiver may not be able to acquire the expected satellite signals (for example, a vehicle parked in a garage or a vessel in a covered berth). Trimble's patented search strategy, also known as a split search, is designed for such situations.

If the receiver does not acquire the expected set of satellites within 5 minutes of power-on, some of the eight tracking channels continue to search for the expected satellites (warm search) while the remaining channels are directed in a cold start search. This strategy minimizes the time to first fix in cases where the stored almanac, position and time are invalid. The stored information is flushed from memory, if the cold start search proves effective and the warm search fails.

4.2.4 Hot Start

A hot start strategy applies when the SVeeEight Plus GPS receiver has been powered down for less than 60 minutes, and the almanac, position, ephemeris, and time are valid. The hot start search strategy is similar to a warm start, but since the ephemeris data in memory is considered current and valid, the acquisition time is typically less than 20 seconds.

4.3 Satellite Mask Settings

Once the SVeeEight Plus GPS receiver has acquired and locked onto a set of satellites, and has obtained a valid ephemeris for each satellite, it outputs regular position, velocity and time reports according to the protocol selected.

The default Satellite Masks observed by the SVeeEight Plus GPS receiver are listed in Table 4-1. These masks serve as the screening criteria for satellites used in fix computations and make sure that position solutions meet a minimum level of accuracy. The receiver only outputs position, course, speed and time when a satellite set can be acquired which meets all of the mask criteria. The Satellite Masks can be adjusted in GPS receivers accepting the TSIP protocol. (See Key Setup Parameters or Packet BB, page A-13.)

Table 4-1 Default Satellite Mask Settings

Mask	Setting
Elevation	5°
SNR	2
PDOP	12
PDOP Switch	5

4.3.1 Elevation Mask

Satellites below a 5° elevation are not used in the position solution. Although low elevation satellites can contribute to a lower/better PDOP, the signals from low elevation satellites are poorer quality, since they suffer greater tropospheric and ionospheric distortion than the signals from higher elevation satellites. These signals travel further through the ionospheric and tropospheric layers.

In addition, low elevation satellites can contribute to frequent constellation switches, since the signals from these satellites are more easily obscured by buildings and terrain. Constellation switches can cause noticeable jumps in the position output. Since worldwide GPS satellite coverage is generally excellent, it is not usually necessary to use satellites below a 5° elevation to improve GPS coverage time. In some applications, like urban environments, a higher mask may be warranted to minimize the frequency of constellation switches and the impact of reflected signals.

4.3.2 SNR Mask

Although the SVeeEight Plus GPS receiver is capable of tracking signals with SNRs as low as 0, the default SNR mask is set to 2 to eliminate poor quality signals from the fix computation and minimize constellation switching. Low SNR values can result from:

- Low elevation satellites
- Partially obscured signals (dense foliage)
- Multi-reflected signals (multi-path)

The distortion of signals and the frequent constellation switches associated with low-elevation satellites were discussed above. In mobile applications, the attenuation of signals by foliage is typically a temporary condition. Since the SVeeEight Plus GPS receiver can maintain lock on signals with SNRs as low as 0, it offers excellent performance when traveling through heavy foliage.

Multi-reflected signals, also known as multi-path, can degrade the position solution. Multi-path is most commonly found in urban environments with many tall buildings and a preponderance of mirrored glass, which is popular in modern architecture. Multi-reflected signals tend to be weak (low SNR value), since each reflection attenuates the signal. By setting the SNR mask to 2 or higher, the impact of multi-reflected signals is minimized.

4.3.3 DOP Mask

Position Dilution of Precision (DOP) is a measure of the error caused by the geometric relationship of the satellites used in the position solution. Satellite sets that are tightly clustered or aligned in the sky have a high DOP and contribute to a lower position accuracy. For most applications, a DOP mask of 10 offers a satisfactory trade-off between accuracy and GPS coverage time. With world-wide GPS coverage now available, the DOP mask can be lowered even further for many applications without sacrificing coverage. For differential GPS applications, DOP related error can be the major contributor to position error. For differential GPS applications requiring the highest level of accuracy, the DOP mask should be set to 7 or below.

4.3.4 PDOP Switch

The default positioning mode for the SVeeEight Plus GPS receiver is Automatic. In this mode, the receiver attempts to generate a 3Dimensional (3D) position solution, when four or more satellites meeting the mask criteria are visible. If such a satellite set cannot be found, the receiver automatically switches to 2-dimensional (2D) mode. The PDOP switch establishes the trade-off between 3D positioning and PDOP. With the PDOP Switch set to 6, the receiver computes a 2D position with a HDOP below 6 rather than a 3D position with a PDOP greater than 6, even when four or more satellites are visible.

Note – PDOP Switch is only used in Auto mode.

4.4 Standard Operating Modes

The tracking mode controls the allocation of the receiver's tracking channels and the method used for computing position fixes. The output of GPS data is controlled by two operating modes:

- Fix Modes (2D, 3D, or Automatic)
- Differential GPS Mode (On, Off, or Auto)

4.4.1 Fix Modes

The SVeeEight Plus GPS receiver offers three positioning modes: 2D Manual, 3D Manual, and Automatic 2D/3D. Automatic 2D/3D is the default mode for the receiver. The positioning mode can be modified in receivers accepting TSIP commands. See Appendix A, Trimble Standard Interface Protocol for more information.

2D Manual

In 2D Manual mode, the SVeeEight Plus GPS receiver only generates two-dimensional (2D) position solutions (latitude and longitude only), regardless of the number of visible satellites. If the altitude is not entered, the receiver uses zero as the default altitude. The greater the deviation between the actual and default altitudes, the greater the error in the 2D position. For TSIP applications, enter local altitude in MSL/HAE via TSIP packet 2AH (see Appendix A, Trimble Standard Interface Protocol).

Note – 2D Manual mode is not recommended for differential GPS applications since any deviation in altitude causes a significant error in the latitude and longitude. Only use the 2D Manual mode for flat land or marine applications where the elevation is known or constant. For DGPS applications, the 3D Manual mode is the recommended positioning mode for the highest level of accuracy.

3D Manual

In 3D Manual mode, the SVeeEight Plus GPS receiver only generates three-dimensional (3D) position solutions (latitude, longitude, and altitude). A 3D solution requires at least four visible satellites which pass the mask criteria. If less than four conforming satellites are visible, the receiver suspends position data outputs. 3D Manual mode is recommended for differential GPS applications requiring the highest level of accuracy.

2D/3D Automatic

The default operating mode for the SVeeEight Plus GPS receiver is 2D/3D Automatic. In this mode, the receiver attempts to generate a three-dimensional (3D) position solution, if four or more satellites meeting the mask criteria are visible. If only three satellites are visible that meet the mask criteria, the receiver automatically switches to two-dimensional (2D) mode and uses the last calculated altitude, if available, or the default altitude in the position solution. In 2D/3D Automatic mode, the PDOP switch is active.

4.5 Differential GPS Operating Modes

The default mode for the SVeeEight Plus GPS receiver is DGPS Automatic. The receiver supports three DGPS Modes: On, Off, and Automatic. The mode can be changed by issuing the appropriate TSIP command. See Appendix A, Trimble Standard Interface Protocol for information. The three DGPS operating modes are described below.

4.5.1 DGPS On

When DGPS On is selected, the SVeeEight Plus GPS receiver only provides differential GPS solutions. If the source of correction data is interrupted or becomes invalid, the receiver suspends all output of position, course and speed data. When a valid source of correction data is restored, the receiver resumes outputting corrected data.

4.5.2 DGPS Off

When DGPS Off is selected, the SVeeEight Plus GPS receiver does not provide differential GPS solutions, even if a valid source of correction data is supplied. In this mode, the receiver only supples standard GPS data.

4.5.3 DGPS Automatic

DGPS Automatic is the default operating mode for the SVeeEight Plus GPS receiver. In this mode, the receiver provides differential GPS solutions when valid correction data is available. If a set of differentially correctable satellites cannot be found which meets the satellite mask settings, the receiver outputs standard GPS solutions. The receiver automatically switches between DGPS and standard GPS based on the availability of valid correction data.

4.5.4 Differential GPS Operation

The SVeeEight Plus GPS receiver is capable of accepting and decoding RTCM SC-104 data. RTCM SC-104 is an industry standard protocol for differential correction data. The receiver is configured to accept RTCM SC-104 correction data over Port 2. Alternatively, you can use TSIP packets 60 and 61 or the TAIP and DD messages to input differential corrections through the primary serial port.

4.6 Position Accuracy

GPS position accuracy is degraded by atmospheric distortion, satellite and receiver clock errors, and Selective Availability (SA). Effective models for atmospheric distortion of satellite signals have been developed to minimize the impact of tropospheric and ionospheric effects. The impact of satellite clock errors is minimized by incorporating the clock corrections transmitted by each satellite used in the position solution. SA is the most significant contributor to position error and cannot be effectively combated except with differential GPS.

4.6.1 Selective Availability (SA)

The U.S. Department of Defense, through a program called Selective Availability, intentionally degrades GPS accuracy for civilian users. The SA program creates position errors by modifying the apparent position of each satellite and introducing random dither into each satellite's clock.

In extreme cases all sources of error (natural, PDOP, and SA) can combine to produce large position errors. The DOD's definition of accuracy under SA is 100 meters 2 dRMS (horizontal 2 dimensional, 95% of the time). In April 1996, the U.S. government approved plans for disabling SA.

4.6.2 Differential GPS (DGPS)

Differential GPS is an effective technique for overcoming the effects of SA and other sources of position error. DGPS relies on GPS error corrections transmitted by a reference station placed at a known location. The reference station compares its GPS position solution to its precisely surveyed position and calculates the error in each satellite's range measurement. The industry standard protocol for GPS correction data is RTCM SC-104.

The GPS corrections are broadcast to mobile GPS receivers in neighboring areas. The mobile receivers incorporate the GPS corrections in their position solution to achieve excellent accuracy. For marine applications, corrections are typically modulated on marine radio beacon broadcasts. For land-based applications, the correction data can be transmitted over FM sub-carrier, cellular telephone or dedicated UHF or VHF radio links.

DGPS can reduce position error to under 5 meters, 95% of the time under steady state conditions. The DGPS accuracy is highly dependent on the quality and age of the differential corrections and the proximity of the mobile receiver to the reference site.

4.7 Coordinate Systems

Once the SVeeEight Plus GPS receiver achieves its first fix, it is ready to commence output of position, velocity, and time information. This information is output over serial communication channel in either the TSIP, TAIP, or NMEA protocol, as determined by the settings of the receiver. These protocols are defined in the following Appendices:

- TSIP - Appendix A, Trimble Standard Interface Protocol (TSIP)
- TAIP - Appendix A, Trimble ASCII Interface Protocol (TAIP)
- NMEA - Appendix E, NMEA 0183

To change from one protocol to another, please see Configuring the SVeeEight Plus GPS Protocols, page 3-8.

4.7.1 TSIP Coordinate Systems

TSIP has the widest choice of coordinate systems. The output format is chosen by TSIP command 0x35. The output formats include the following:

- LLA position — Latitude, longitude, altitude (LLA) according to the WGS ellipsoid or one of over a hundred other datums. See Datums, page A-84 for a list of available datums. Altitude can be chosen to be height above ellipsoid (HAE) or height above mean sea level (MSL).
- ENU velocity — ENU velocity is the velocity in East, North, and Up coordinates. These coordinates are easily converted to speed and heading.
- ECEF position and velocity — ECFF position and velocity is Earth-Centered, Earth-Fixed frame is a Cartesian coordinate frame with its center at the earth's center, the z-axis through the North Pole, and the x-axis through longitude 0 degrees, latitude 0 degrees. Velocity is reported relative to the same axes.
- UTM — Universal Transverse Mercator (UTM) is a mapping coordinate system used by many government agencies.

There are also two time coordinate systems:

- GPS time — GPS time is determined by an ensemble of atomic clocks operated by the Department of Defense (DOD).
- UTC time — UTC time is the world standard maintained by an ensemble of atomic clocks operated by government organizations around the world.

GPS time is steered relative to Universal Coordinated Time (UTC). GPS does not recognize leap seconds resulting in a situation where GPS time is currently 13 seconds ahead of UTC time. Time tags for most output messages can be in either UTC time or GPS time, as chosen by TSIP command 0x35.

4.7.2 NMEA 0183

The NMEA 0183 protocol only supports LLA format and UTC time. Velocity is always described as horizontal speed and heading. Vertical speed is not output.

4.7.3 TAIP

The TAIP protocol only supports the LLA coordinate system. Timetags are GPS, except for the TM time mark message.

4.8 Performance Characteristics

4.8.1 Update Rate

The SVeeEight Plus GPS receiver computes and outputs position solutions once per second, on the second. NMEA outputs can be scheduled at a slower rate using TSIP command OX7A. Refer to Appendix A, Trimble Standard Interface Protocol.

4.8.2 Dynamic Limits

The dynamic operating limits for the SVeeEight Plus GPS receiver are listed in Table 4-2. These operating limits assume that the GPS receiver is correctly embedded and that the overall system is designed to operate under the same dynamic conditions.

Table 4-2 SVeeEight Plus GPS Operating Limits

Operation	**Limit**
Acceleration	4 g (39.2 m/s^2)
Jerk	20 m/s^3
Speed	500 m/s
Altitude	18,000 m

Note – The SVeeEight Plus GPS firmware contains an algorithm that allows the speed limit or altitude limit to be exceeded but not both. This allows the receiver to be used in high altitude (research balloon) applications without a special factory configuration.

4.8.3 Re-Acquisition

Re-acquisition time for a momentary signal blockages is typically under 2 seconds.

When a satellite signal is momentarily interrupted during normal operation, the receiver continues to search for the lost signal at the satellite's last known Doppler frequency. If the signal is available again within 15 seconds, the receiver re-establishes tracking within two seconds. If the lost signal is not re-acquired within 15 seconds, the receiver initiates a broader frequency search. The receiver continues to search for the satellite until it falls below the Elevation Mask.

4.9 GPS Timing

In many timing applications, such as time/frequency standards, site synchronization systems and event measurement systems, GPS receivers are used to discipline local oscillators.

The GPS constellation consists of 24 orbiting satellites. Each GPS satellite contains a highly-stable atomic (Cesium) clock, which is continuously monitored and corrected by the GPS control segment. Consequently, the GPS constellation can be considered a set of 24 orbiting clocks with worldwide 24-hour coverage.

GPS receivers use the signals from these GPS clocks to discipline the GPS receiver’s crystal oscillator. GPS receivers like the SVeeEight Plus GPS output a highly accurate timing pulse (PPS) generated by its internal oscillator, which is constantly corrected using the GPS clocks. This timing pulse is synchronized to UTC within ±500 ns.

GPS receivers are also used to synchronize distant clocks in communication or data networks. This synchronization is possible since all GPS satellite clocks are corrected to a common master clock. Therefore, the relative clock error is the same, regardless of which satellite or satellites are used. For timing applications requiring a common clock, GPS is the ideal solution.

GPS time accuracy is bounded by the same major source of error affecting position accuracy, Selective Availability. The position and time errors are related by the speed of light. Therefore, a position error of 100 meters corresponds to a time error of approximately 333 ns. The hardware and software implementation affects the GPS receiver's PPS accuracy level. The receiver's clocking rate determines the PPS steering resolution.

The SVeeEight Plus GPS receiver clocking rate is 3.126 MHz. This rate corresponds to a steering resolution of ±160 ns. Software techniques such as over-determined clock algorithm can achieve PPS accuracy better than Selective Availability because more satellites are used to give a higher timing accuracy.

4.9.1 Serial Time Output

Both the TSIP, TAIP, and NMEA protocols include time messages. Refer to Report Packet 0x41 - GPS Time, page A-33 or ZDA - Time & Date, page E-8 for a description of the time reports for each protocol and the TAIP TM message.

Note – GPS time differs from UTC (Universal Coordinated Time) by a variable, integer number of seconds UTC = (GPS time) - (GPS UTC offset).

As of January 1999, the GPS UTC offset was 13 seconds. The offset has historically increased by 1 second about every 18 months. System designers should plan to read the offset value as a part of the timing interface to obtain UTC. The GPS week number is in reference to a base week (Week #0), starting January 6, 1980.

4.9.2 Timing Pulse Output (PPS)

A pulse-per-second (PPS), ten microsecond wide, open collector pulse is available on the SVeeEight Plus GPS 9-pin output port. The pulse is sent once per second and the falling edge of the pulse is synchronized with UTC. The falling edge is typically less than 20 ns wide.

4.10 System Architecture

The SVeeEight Plus GPS receiver (see Figure 4-1) uses eight processing channels operating on the L1 frequency of 1575.42 MHz and which use the coarse acquisition (C/A) code. The receiver uses custom integrated circuitry designed by Trimble to track the GPS satellite signals. These ICs also contain support circuitry for the navigation processor. An integrated 32-bit microprocessor is used for tracking, computing a position, and performing the I/O operations.

The receiver receives the GPS satellite signals through the antenna feed line connector, amplifies the signals, and then passes them to the RF down converter. A highly stable crystal reference oscillator operating at 12.504 MHz is used by the down converter to produce the signals used by the 8-channel signal processor. The 8-channel signal processor tracks the GPS satellite signals and extracts the carrier code information as well as the navigation data at 50 bits per second.

Operation of the tracking channels is controlled by the navigation processor. The tracking channels track the highest eight satellites above the horizon. The navigation processor then uses the optimum satellite combination to compute a position. The navigation processor also manages the ephemeris and almanac data for all of the satellites, and performs the data I/O.

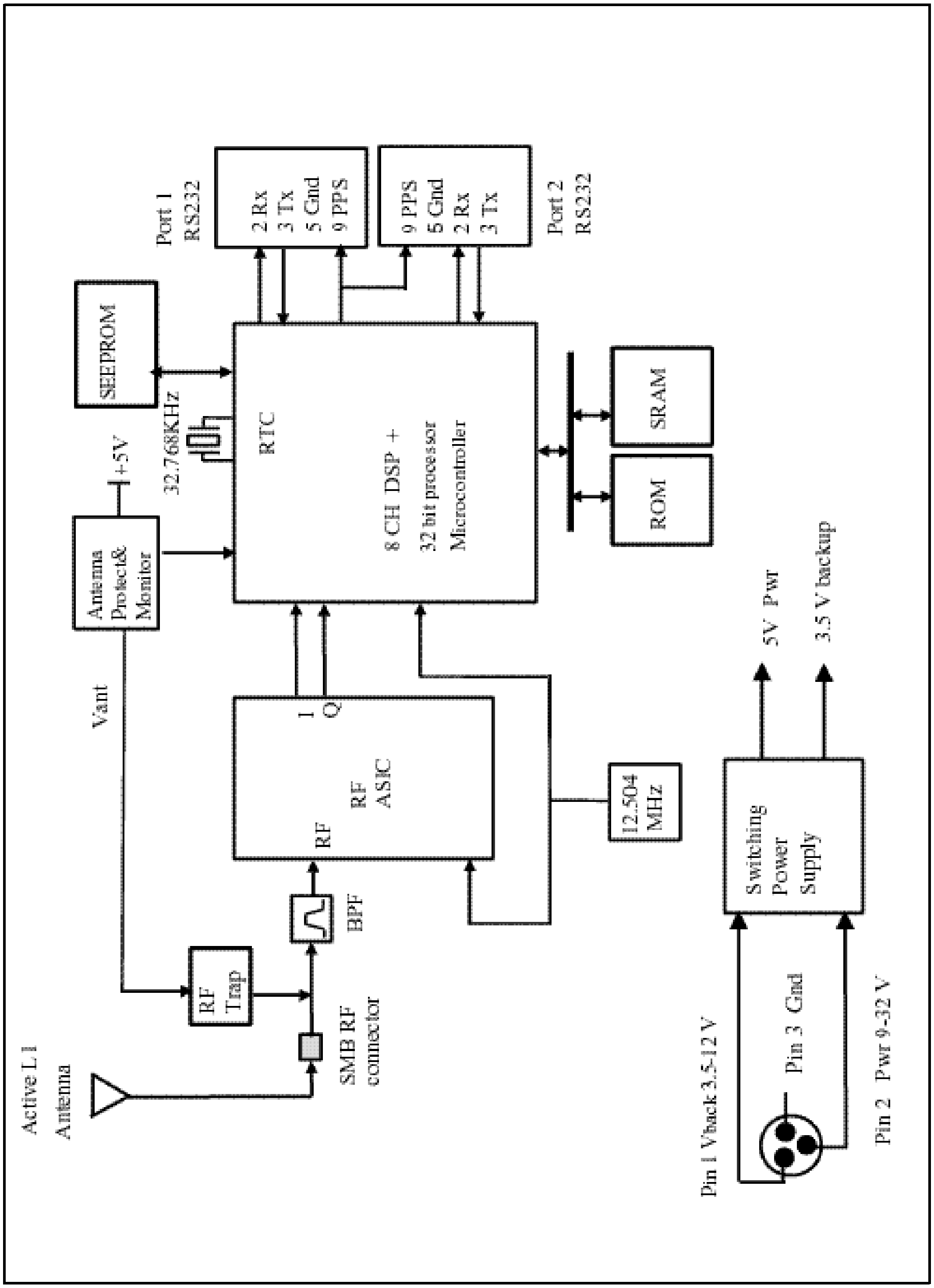

Figure 4-1 SVeeEight Plus GPS Block Diagram