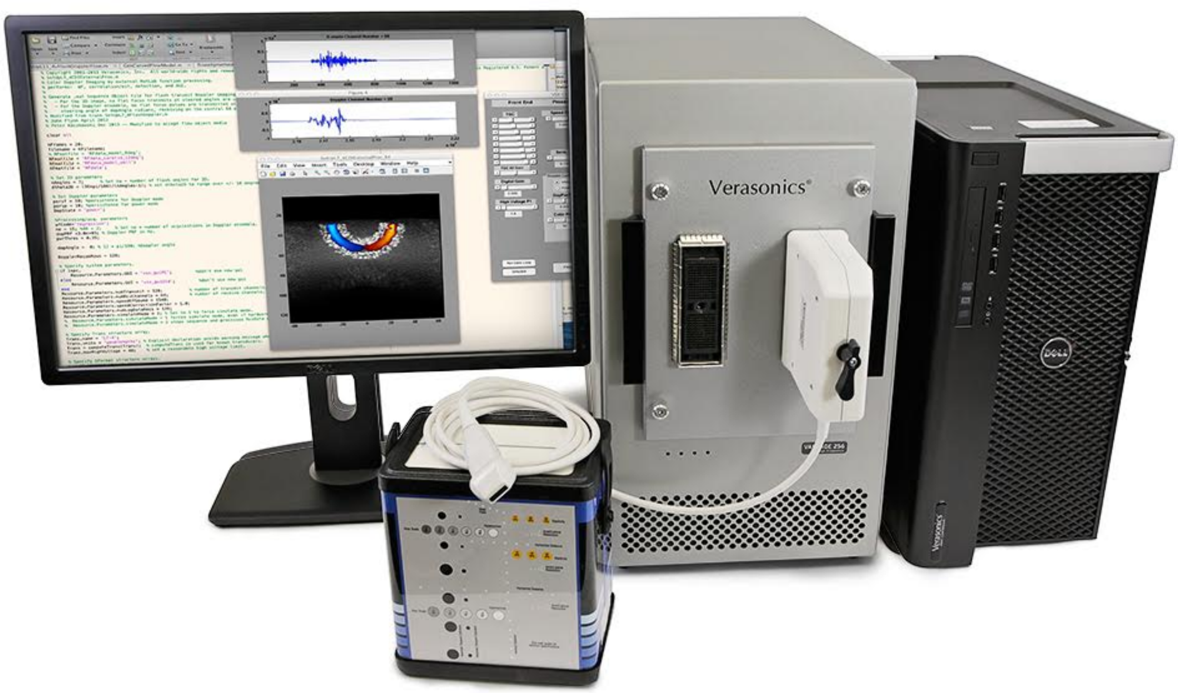
Vantage Product Specification



This specification document applies to the Verasonics Vantage Product family, at system software release level 3.3.0.

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This document covers the features and performance specifications of the Vantage products; refer to the separate "Vantage User Manual" and "Vantage Sequence Programming Manual" documents for instructions on how to program the system to use these features.

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1 System Configurations and Optional Features

1.1 Overview

The Vantage system is made up of three primary components:

Vantage hardware system "chassis assembly", as provided by Verasonics. The system is available in four different basic configurations, with several optional add-on features as described in more detail in the following subsections.

Host Computer, with an appropriate operating system and the required software applications and utilities installed on it. The host computer can be purchased through Verasonics along with a system order, or the customer can provide it.

Vantage system software, provided by Verasonics through an online server from which the customer can download and install the software on their host computer. If the host computer is purchased through Verasonics, it will be shipped to the customer with the Vantage software pre-installed. The Vantage software is installed as a single package that supports all available hardware system configurations; at system startup the software automatically configures itself for use with the specific hardware configuration that is present.

1.2 Vantage Hardware System Basic Configurations

The Vantage hardware system is available in four configurations, as listed below. All of these configurations use the same chassis size and PCI-express ("PCIe") interface to the host computer. Unless specifically noted otherwise, all aspects of transmit-receive per-channel performance and all other system features and options are identical for all four configurations.

An existing Vantage system can be upgraded to a different system configuration, but to do this the system must be returned to Verasonics (or an authorized Verasonics service representative) for installation and testing of the new hardware configuration.

- **Vantage 256 System:** This configuration provides 256 independent transmit channels and 256 independent receive channels.
- **Vantage 128 System:** This configuration provides 128 independent transmit channels and 128 independent receive channels.
- **Vantage 64 LE System:** This configuration provides 128 independent transmit channels and 64 independent receive channels, with switching for each receive channel to one of two transducer elements allowing receive data acquisition from the desired 64 element subset of a 128-element transducer. Two "synthetic aperture" transmit-receive acquisition events can be combined to provide round-trip acquisition through all 128 elements.
- **Vantage 64 System:** This configuration provides 64 independent transmit channels and 64 independent receive channels.

All four basic system hardware configurations are provided with the "UTA" (Universal Transducer Adapter) feature allowing the installation of a variety of connector modules supporting different types of ultrasound transducers. The UTA feature is described in section 1.3 below, with a listing of UTA modules currently available.

All system configurations use the same “acquisition modules” installed within the system to provide the per-channel transmit and receive electronics. There are four types of acquisition modules currently available; any of the four basic system configurations can be configured with any of these four acquisition module types (with a few exceptions), as listed below:

- **Standard Frequency (or “SF”):** Operating frequency range approximately 0.5 to 25 MHz; available on all four system configurations.
- **High Frequency (or “HF”):** Operating frequency range approximately 2 to 45 MHz; available on all system configurations except Vantage 64
- **Low Frequency (or “LF”):** Operating frequency range approximately 50 KHz to 1.5 MHz; available on all four system configurations
- **HIFU:** Standard Frequency acquisition modules with additional heat sinks to support the very high transmit power levels needed for HIFU applications; available only on Vantage 128 and Vantage 256 systems

Detailed transmit and receive performance specifications for each available frequency range are provided in sections 3.1 and 4.1 of this document; the HIFU features are described in section 1.4.

1.3 Vantage System UTA Configuration

All Vantage hardware systems built since the Fall of 2015 are provided in a “UTA” (Universal Transducer Adapter) configuration providing user-replaceable transducer connector modules to allow the system to be used with a range of different connector types and pinouts. This allows use of the system with several commercially available probe families as well as with customized transducer interfaces developed by an individual customer or provided by Verasonics. Multiple connector modules (typically referred to as “UTA Modules”) can be purchased for use with the same system. The UTA module attaches to the front of the system and is held in place with thumbscrews, so a system can easily be reconfigured from one UTA module type to another in just a few minutes with no tools required.

Note that older Vantage systems (generally those built before the Fall 2015) did not have the UTA feature. Instead they had fixed, non-replaceable probe connectors built into the system. The functionality of the connectors on these older systems is identical to the UTA 260-S module for Vantage 64 LE and Vantage 128 systems, or the UTA 260-D module for Vantage 256 systems. If desired, these older systems can be upgraded to add the UTA feature. Contact Verasonics for pricing and availability of the upgrade.

The following UTA modules are available and supported through the Vantage 3.2.1 software release (older software releases will not function with all of these modules):

- **UTA 260-S: single Verasonics 260 pin, 128 channel Connector (HDI compatible)** For use with Vantage 128 and Vantage 64LE systems. With this UTA module installed, system functionality is identical to an older pre-UTA system with the captive HDI connector.

- **UTA 260-D: dual Verasonics 260 pin, 128 channel Connectors (HDI compatible)** For use with Vantage 256 systems. With this UTA module installed, system functionality is identical to an older pre-UTA Vantage 256 system with two captive HDI connectors.
- **UTA 260-MUX: single Verasonics 260 pin, 128 channel Connector (HDI compatible)** For use only with the Vantage 64 system. This module includes HVMux switching, to allow a Vantage 64 system to have access to all 128 element signals at the connector. With this module, the Vantage 64 system can be used with all probes supported by the higher channel count system configurations through the UTA 260-S module with the exception of those using internal HVMux switching (i.e. the UTA 260-MUX module can be used only with probes having 128 or fewer directly connected elements).
- **UTA 360: Cannon 360 pin, 256 channel ZIF Connector** For use with Vantage 256 systems, allowing connection of a 256 element probe through a single connector. Compatible with the MS family of commercial probes.
- **UTA 408: Cannon 408 pin, 256 channel ZIF Connector** For use with Vantage 256 systems, allowing connection of a 256 element probe through a single connector. This module can also be used with Vantage 64 LE and Vantage 128 systems, but only with probes having 128 or fewer elements.
- **UTA 408-GE: 408 pin, 256 channel ZIF Connector** compatible with the GE "-D" family of ultrasound probes. For use with Vantage 256 systems, allowing connection of a 256 element probe through a single connector. This module can also be used with Vantage 64 LE and Vantage 128 systems, but only with GE probes having active apertures of 128 or fewer elements.
- **UTA 160-DH/32 LEMO** to support NDT (Non Destructive Testing) applications of the Vantage system. This module provides two Hypertronics 160 pin, 128 channel connectors and an array of 32 Lemo coax connectors for use with single-element transducers. The Hypertronics connector and pinout is compatible with many commercially available transducers for use in NDT applications. This module can be used with all four Vantage system configurations, but the number of elements that can actually be used at each Hypertronics connector will be restricted on the lower channel count systems.

Additional UTA adapters are being developed and will be offered in the future, including documentation and guidelines a customer can use to develop their own custom adapter.

1.4 HIFU Configuration and Extended Transmit Option

Two different extra-cost options are available on the system to allow transmit at higher power levels. These options add the power supply and system software control capabilities to allow high transmit power, but the transmit channels themselves remain identical to those used in the imaging-only standard frequency system configuration and thus there is no impact to the imaging transmit performance as a result of adding either transmit option. To protect the system hardware from potential damage due to the high power levels available, a self-protection limit checking software function is included with both of these options. This function evaluates a user's event sequence before it is executed, to verify that the system's safe operating limits will not be exceeded. The limit checking function is only intended to protect the system from damage; it does not protect the transducer from overheating or damage and does not limit the actual acoustic output levels from the transducer.

Note that the HIFU Configuration is not available on Vantage 64 LE or Vantage 64 systems, and only supports the “Standard Frequency” operating frequency range.

The following specifications apply to both the Extended Transmit Option and the HIFU hardware configuration:

Per-Channel Transmit Performance remains identical to the specifications given in the standard frequency range Transmit Performance sections of this document. However, full power output for very long burst durations is only available in the frequency range from 1 to 4 MHz. Maximum power levels achievable above 4 MHz may be more limited, depending on the actual burst duration, aperture size, and repetition rate.

TPC Profile 5 is required for transmit burst durations and power levels that exceed the capacity of the imaging transmit supply associated with TPC profiles 1 through 4. Profile 5 disables the transmit supply used for normal imaging/Doppler transmit, and connects the dedicated supply used for high-power transmit. Imaging/Doppler acquisition sequences can be interleaved with HIFU transmit, by transitioning between profile 5 and an imaging TPC Profile whenever desired in an acquisition sequence.

TPC Profile 5 Transition Time (both into and out of profile 5) depends on the difference between the two transmit voltages, from a few hundred microseconds for very close voltage levels up to 10 to 15 milliseconds for a nearly 100 Volt difference. For applications that cannot tolerate this transition interval, imaging acquisitions can be done while remaining in profile 5 (but with the potential for slightly degraded Doppler performance, and the constraint of using the same voltage level).

Transducer Load Impedance must be specified in the Trans structure for Profile 5 transmit. Available per-channel output power varies in direct proportion to the load impedance. Therefore the self-protection limit check algorithms must know the load impedance to determine whether the operating state is within allowable limits.

Simultaneous Receive Functionality can be enabled during a HIFU transmit event when required by the user's application. The full receive performance specified in section 5 is available during transmit (to the extent it is not compromised by crosstalk in the transducer and transducer element signal wiring).

Extended Transmit Option

An auxiliary transmit power supply and a large energy storage capacitor are added to the system, mounted within the system chassis. When selected (by switching to TPC Profile 5), this transmit power source allows the use of transmit sequences with durations of up to several milliseconds at transmit burst power levels typically used for short imaging transmit bursts (up to several thousand Watts for a large aperture). An interval must be allowed between Extended Transmit bursts that is long enough to allow the power supply to recharge the energy storage capacitor before the next burst.

HIFU & Extended Transmit Options are Mutually Exclusive An external HIFU power supply cannot be used on a system that has been configured for the Extended Transmit Option using the internal auxiliary transmit power supply.

Maximum Transmit Power available from the internal auxiliary supply is approximately 50 Watts, when operating at transmit voltages near 100 Volts. At lower transmit voltages the available power will decrease proportionately, since the maximum current available from this supply is about 0.5 Amp. The maximum power available during a transmit burst will therefore depend directly on the Extended Transmit duty cycle (transmit burst duration divided by idle time between bursts).

Transmit Voltage Droop During Transmit Burst will occur, since the burst is powered primarily from the 15 milliFarad energy storage capacitor. The rate of droop will vary directly with the transmit supply current being drawn from the capacitor during the burst.

HIFU Transmit Configuration

The functionality for this configuration is identical to the Extended Transmit Option described above, except that an external 1200 Watt power supply is provided with the system as the transmit power source for TPC Profile 5 transmit events. This configuration will allow continuous transmit at output power levels of up to 1000 Watts. With this configuration the system itself can provide up to 2000 Watts of continuous output power if the user provides an external power supply with additional capacity.

HIFU & Extended Transmit Options are Mutually Exclusive The internal auxiliary transmit power supply cannot be used on a system that has been configured for the HIFU Transmit Option using the external HIFU power supply.

Windows OS Only For all Vantage software releases to date, the HIFU configuration is only available for use with the Windows OS.

External Power Supply provided with the HIFU Transmit Configuration is AIM-TTI model QPX600D (www.tti-test.com), with 1200 Watt output capacity. Refer to the manufacturer's data sheet for detailed specifications, size and weight, etc. for this supply.

software Remote Control The Verasonics system software provides direct remote control of the external power supply, through a USB connection from the supply to the host computer. This remote control interface allows the Vantage control software to set the power supply output voltage level, output current limit, and output enable/disable status.

Independent AC Line Power The external power supply requires its own AC line power connection, independent of the Vantage unit and the host computer. Power supply on/off control must be done manually by the user (or through some other means added to the system by the user). The software Remote Control interface does not provide AC line on/off control. Since a system with the HIFU Configuration as provided by Verasonics requires these separate AC line connections, it is up to the user to provide an isolation transformer or equivalent if needed to meet line isolation and leakage current requirements for a clinical application.

Series/Parallel Output Connection The QPX600D provides two independent outputs, each capable of 600 Watts for output voltages from 12 to 60 Volts or 50 Amps for voltages below 12 Volts. Normally these two outputs are wired in parallel, to allow 1200

Watts of transmit input power to the system at any voltage from 12 to 60 Volts. The system control software also allows the user to make a series connection, allowing 1200 Watt transmit input power at voltages up to the system maximum of 100 Volts but with less power available for voltages below 24 Volts.

Dual Power Supply 2400 Watt Configuration As a semi-custom option, the user can purchase two QPX600D power supplies and connect them both to the system (using either a series or parallel connection as described above) to allow HIFU transmit at input power levels up to 2400 Watts during the burst. The Vantage system software can be configured to provide direct USB remote control of both external supplies for this configuration.

Maximum External Supply Current: 60 Amps RMS

This is the maximum transmit supply current that can be sent to the Vantage unit through the rear panel connector from the external HIFU power supply. The maximum transmit supply current drawn by each individual 64-channel Acquisition Board within the system must not exceed 15 Amps RMS. Peak current during a transmit burst can exceed these limits; the stated RMS limit applies to averaging intervals on the order of 100 milliseconds or longer.

1.5 Software Licensed Options

The Vantage system software includes a licensing feature to restrict use of the system to only those hardware systems and optional features that have been purchased for a specific customer account. These features are controlled through an encrypted “license file” provided by Verasonics and included in the Vantage software installation. Refer to the User Manual for information on the administration of Software Licensed Options, and how to request updates or additions to your license file from Verasonics.

For the Vantage 3.2.1 release, the following options are controlled through the software license file, allowing field upgrades that can easily be installed by the customer:

- Software License, to allow use of a specific Vantage software release. A license for each new software release is free to customers within their warranty period or with an active SLA agreement. When a new software release is distributed to customers entitled to receive it, an updated license file for each individual customer account will be included with the release.

- Hardware License, to allow use of the Vantage software with the specific Vantage hardware system(s) associated with the customer account. This license is keyed to the unique serial number associated with each Vantage hardware system.

- Stand-alone software simulation license, to allow the Vantage software to be installed and used on a customer’s computer that is not connected to a Vantage hardware system. These licenses are keyed to a unique ID code associated with a specific computer.

- Extended Transmit Option, to allow use of TPC Profile 5.

- Arbwave Package (includes ability to use the Arbwave Toolkit for generation and analysis of transmit waveforms using the “arbitrary waveform” capability of the Vantage system, and the Extended Transmit Option to allow use of long-duration arbitrary waveforms)

- Trigger Option (allows use of the external trigger input / output features). This option applies to Vantage 64 and Vantage 64LE systems only; Triggers are a standard feature on Vantage 128 and 256 systems.

- Reconstruction Processing Option (allows use of the proprietary “Recon” function provided by Verasonics). This option applies only to Vantage 64 systems; Reconstruction Processing is a standard feature on Vantage 64 LE, 128, and 256 systems.

2 Host Computer and Software Platform

The Vantage hardware unit cannot function on its own; it must be physically connected to a host computer through a PCIe link, and the host computer must have the Vantage software and required commercial software packages installed, as identified in the following subsections.

2.1 User-Supplied Host Computer

The customer can purchase the Vantage system without a host computer, and provide their own computer for use with the system. In this case, it is the customer's responsibility to install the following required components on their computer:

PCIe host adapter card (provided with the Vantage hardware system) for the PCIe link to the Vantage hardware unit. Must be installed in a PCIe expansion slot in the host computer.

Memory At least 16 GBytes of memory as a minimum; if your application will include very large buffers for RF data and/or image data additional memory should be installed.

CPU Processor(s) must support multicore processing with at least 8 cores, and the SSE 2 vector processing instruction set. Future Vantage software releases will utilize the AVX 2 instruction set, so if you are purchasing a new computer it should support that as well.

software operating system that meets the Verasonics requirements.

Matlab® application software with the signal processing toolkit.

Verasonics application software, drivers, and support utilities (provided by Verasonics with purchase of a system; must be downloaded and installed by the customer if host computer was not purchased through Verasonics).

Other commercial software packages and options, as identified by Verasonics for a particular software release.

Verasonics can provide guidelines and specific examples of makes and models of host computer that are known to work well with the Vantage System. For a customer-supplied computer that is not on the example list, Verasonics cannot guarantee that it will be fully compatible with all requirements for use with the Vantage system.

2.2 Verasonics-Supplied Host Computer

The customer can choose to purchase a host computer through Verasonics, as part of their Vantage system order. In this case Verasonics will provide a host computer that is known to work well with the Vantage system. Before shipping the computer to the customer, Verasonics will pre-install and configure the user-selected Operating System, Matlab®, other required software packages, the Verasonics software and drivers, and the PCIe host adapter card. The user must purchase and activate their own Matlab license for the pre-installed software (and other commercial software licenses as required) before they can use the system.

2.3 Host Computer Operating System Requirements

The Vantage system can be used with any of the following three operating systems (The 3.2.1 Vantage software release was tested on the OS release levels listed here.):

Microsoft Windows 7 Ultimate, 64 bit

Apple MacOS X 10.10.5 "Yosemite" 64 bit, for use with Apple MacPro computers

Linux (open source) Ubuntu version 14.04 LTS, 64 bit

As new commercial OS releases become available, Verasonics will provide incremental Vantage software releases that are compatible with them. These incremental Vantage software releases are available free of charge to Vantage customers within the one year warranty period after purchase of a system, and to any customer who has a currently active service/maintenance contract with Verasonics.

Generally speaking, the Vantage software will usually be backward and forward compatible to older or newer releases of the OS and other required software packages such as Matlab®, but Verasonics cannot guarantee this compatibility. The documentation provided with a particular Verasonics software release will identify any known compatibility problems with specific versions of the OS, Matlab, or other commercial software.

The Verasonics software release and associated installation instructions will also identify any specific OS settings or configuration options that must be used for proper operation of the Vantage system.

It is recommended that the host computer to be used with a Vantage system should not be used for any other applications or purposes, since such use may require different OS settings and/or may utilize resources that are needed for the Vantage system to operate at full performance.

2.4 PCI-express Connection to Host Computer

The system uses a PCI-express interface for connection (through an extension cable and adapter board) to an expansion slot in the host computer. All interaction with the host computer passes through this interface, including DMA transfer of receive data from Vantage system to the host computer, and programming data, commands, and parameter values from the computer to the system. Signals provided through this interface are also used to automatically control the power on/ standby status of the Vantage hardware unit, in response to the power on/off status of the host computer.

The PCIe expansion slot used for the Vantage Host Adapter card must provide either 16 lanes at PCIe Gen 2 speed, or 8 lanes at PCIe Gen 3 speed. (The system will be fully functional in an expansion slot with reduced lane width or speed, but at reduced DMA transfer rate performance.)

A 1-meter PCIe interconnect cable is provided with the Vantage system, for the connection from the host adapter card to the Vantage hardware unit. (It is possible to use a longer interconnect cable, but some customization of system settings may be required for reliable operation at full bandwidth for a different cable. Contact Verasonics for details.)

3. Transmit Specifications: Standard, High, and Low Frequency

Each transmit channel uses a three-level switching transmitter that can drive the transmit output to a programmable voltage level with either positive or negative polarity and can also drive the output actively to ground. The transmitter consists of an H-bridge array of power FET's with the output coupled to the transducer element signal through a transformer. This design ensures a high level of symmetry to minimize even harmonic content in the output signal, and also provides very low loss in the receive path while the transmitter is inactive.

Excitation for the transmitter is provided by a user-programmable "arbitrary waveform generator" that can specify any one of the three output levels independently for every period of the 250 MHz system clock within the transmit waveform. The desired waveform can also be programmed independently for each individual transmit channel.

The 250 MHz clock provides transmit delay resolution of 4 nsec, sufficient for excellent transmit steering and focus performance at frequencies up to 15.625 MHz (1/16 wavelength resolution) and good performance at frequencies up to 31.25 MHz (1/8 wavelength resolution).

The specifications in the following subsections apply all of the frequency range configurations of the system, unless they are specifically identified with a specific frequency range configuration. For clarity, all specifications specific to the standard frequency configuration are highlighted in **green text**, specifications specific to the high frequency configuration are highlighted in **blue text**, and specifications specific to low frequency are highlighted in **orange text**. Any specification in black text applies to all three.

Unless noted otherwise, all per-channel transmit specifications given here apply to all system configurations: Vantage 256, Vantage 128, Vantage 64LE, and Vantage 64.

3.1 Per-Channel Transmit Specifications

All specifications apply only to transmit signals within the specified “full specification” frequency range and system environmental operating conditions, unless noted otherwise.

Operating Frequency Range:

Standard Configuration	**0.5 to 20 MHz**
High Frequency Configuration	**2 to 42 MHz**
Low Frequency Configuration	**50 KHz to 2 MHz**

This is the frequency range over which the transmitter is able to provide a useful level of performance. Note that this range is somewhat broader than the “full specification” frequency range given below. Outside the limits of the full specification range, some aspects of transmit performance (such as channel-to-channel uniformity, maximum output amplitude, or variations in frequency response) may degrade, but this degradation is very gradual with frequency.

Full Specification Frequency Range:

Standard Configuration	**1 to 15 MHz**
High Frequency Configuration	**4 to 30 MHz**
Low Frequency Configuration	**50 KHz to 1.5 MHz**

Unless noted otherwise, this is the frequency range over which all performance specifications given below are fully met.

Maximum Output Level: **190 Volts P-P**

Maximum output voltage at the transducer connector, when driving an open circuit. This level is obtained by programming the internal transmit power supply to its maximum level of 96 Volts.

Transformer Flux Saturation Limit

Standard Configuration	**25 Volt-usec**
High Frequency Configuration	**6.25 Volt-usec***
Low Frequency Configuration	**317 Volt-usec**

At transmit frequencies below the lower end of the full specification frequency range given above, the flux saturation limit may restrict the maximum transmit voltage to less than 96 Volts peak. The amount of reduction will depend on the nature of the transmit waveform, and the relative pulse width of each individual transmit pulse. The system software will analyze the transmit waveform as specified by the user, and automatically reduce the maximum allowed transmit voltage if necessary to stay within the limit.

* Early versions of the high frequency configuration (built before approximately May 2014) have a lower flux saturation limit of 4.2 Volt-usec.

Minimum Output Level: **3 Volts P-P**

At outputs below this level, channel-to-channel uniformity will be significantly degraded. There is also a system hardware design restriction that prevents the transmit power supply from being set below 1.6 Volts during operation. The nominal peak output voltage that can be expected at the transducer connector will be the system transmit supply voltage setting, minus 0.8 Volts drop through the transmit clamp diodes at the receive path input, minus the expected voltage drop through the transmit source impedance based on the output current through the transducer load impedance.

Output Pulse Duration:

Standard Configuration	**3 to 175 Clock periods**
High Frequency Configuration	**3 to 175 Clock periods**
Low Frequency Configuration	**3 to 2500 Clock periods**

The transmit waveform generator produces a three-level (+HV, 0, -HV) square wave output at a 250 MHz clock rate, allowing 4 nsec resolution for individual output pulse durations in the range from 12 nsec (3 clock periods) to 0.7 usec (175 clock periods), **or 10 usec (2500 clock periods) for low frequency.** Output pulses of 1 or 2 clock periods are not allowed because of the transition time limitations of the transmit hardware (a 2-clock pulse will produce a small output with amplitude varying dramatically from channel to channel, and a 1-clock pulse will typically produce no output at all). Individual output pulses longer than the stated maximum are not allowed because of the AC coupling of the gate drive signal to the transmit FET's. Note however that the output transformer flux saturation limit may reduce the usable maximum pulse duration to less than this 175 clock maximum.

There is no similar restriction on the zero-state interval in between active output pulses. It can be as short as 0, 1, or 2 clock periods, and can also be set as long as 10,000 clock periods or 40 usec.

Output Source Impedance:

Standard Configuration	**8 Ohms plus 1.4 uH (typical)**
High Frequency Configuration	**9 Ohms (typical)**
Low Frequency Configuration	**22 Ohms plus 7.7 uH (typical)**

This is an approximate representation of the transmit source impedance from the system, as presented to the transducer connector. Within the lower half of the full specification frequency range, the transmit output can be modeled as an ideal voltage source driving the transducer connector through the series resistance and inductance as stated above. The voltage source in this model will be producing an ideal 3-level square wave as defined by the TW.PulseCode waveform array, with +/- amplitudes of 0.8 Volt less than the system transmit HV supply setting for the TPC Profile being used. The 0.8 Volt reduction represents the drop across the clamp diodes that form part of the transmit output signal return path (shunting the input of the receive path). Note that at transmit levels with peak output currents less than about 50 mA (and also during the zero-crossings of the transmit output current), the 0.8 Volt fixed voltage drop will no longer be an accurate representation of the effect of the clamp on the output waveform.

This simple model of the source impedance also assumes a load impedance no higher than a few hundred Ohms. At higher load impedance levels (and especially in the case of an open circuit!), other factors such as shunt capacitance become significant, and will result in an output waveform considerably different than predicted by the model defined above.

There is also a ferrite bead in series with the transmit output, to suppress EMI at VHF frequencies. Below 15 MHz the effect of this bead is accurately modeled as a small series inductance, included in the source impedance model stated above. Above 15 MHz the ferrite bead becomes more lossy and thus more resistive than inductive; as a result the source impedance at high frequencies will become higher and less reactive than implied by the simple model of a fixed series resistance and inductance.

For the High Frequency Configuration (and at higher transmit frequencies for the standard frequency configuration), the PCB traces from the transmitter out to the transducer connector behave more like a transmission line than some lumped series inductance and resistance. This results in a broader frequency response but with additional loss, compared to the simple L, R model given above.

When driving a 50 Ohm resistive load at the transducer connector, the transmit output from the high frequency configuration can be characterized as a 9 Ohm resistive source impedance, with approximately 8 nsec transition times for the three-level square wave output. At the minimum allowed pulse duration of 3 clock periods (12 nsec), the output pulse will look like a triangle wave, 20 nsec long at the base and with the peak at the transmit HV level. At transmit voltages below about 20 Volts gate driver feedthrough alters the shape of the waveform significantly, resulting in a longer transition time (the gate drive feedthrough is inverted from the expected transmit output, and thus at minimum HV for a very short pulse the output will actually appear to be inverted). Since gate drive feedthrough is at a fixed amplitude regardless of the HV setting, it has negligible effect on the shape of the output waveform for HV settings above 20 Volts.

Maximum Peak Output Current: 2 Amps

This is the maximum instantaneous peak output current the transmitter can reliably provide. It implies that for a transducer load impedance of less than 50 Ohms, the maximum allowed transmit voltage will have to be reduced to less than 100 Volts, to stay within the 2 Amp limit.

Maximum Continuous Output Current: 0.4 Amp RMS

Note this RMS value is evaluated over the entire event sequence including the transmit idle time in a typical PRI, and thus is often much lower than the RMS current evaluated just over the duration of the transmit burst. This limit restricts the maximum continuous output current an individual channel can provide for HIFU transmit applications with very long transmit durations at high duty cycles. For a 50 Ohm transducer load impedance, this implies a per-channel output power level to the transducer of 8 Watts. Note that depending on the operating state, other system constraints may prevent the individual channels from reaching this limit (for example, if all transmit channels are active the transmit power supply may not have enough capacity to drive them to this limit). For an imaging or 'push' application with short burst durations and low duty cycle (duty cycle defined as burst duration / PRI), the peak output current limit will be more restrictive than this continuous current limit.

Channel-to-Channel Amplitude Variability

Standard Freq. Configuration	**+/-0.3 dB (1 to 8 MHz);**
	+/-0.6 dB (8 to 15 MHz)
High Frequency Configuration	**+/-0.3dB (4 to 15 MHz);**
	+/-0.6 dB (15 to 30 MHz)
Low Frequency Configuration	**+/-0.5 dB (50 to 200 KHz);**
	+/-2.0 dB (1 MHz)*

Maximum output amplitude variation (max vs. min) over all channels, when driving a 50 Ohm resistive load with a periodic repeating transmit waveform.

* For frequencies above 200 KHz on the Low Frequency Configuration, the channel-to-channel variability is dominated by variation in the nominal 7.7 uH leakage inductance of the individual output transformers. As a result, the variability in both phase and amplitude will increase in direct proportion to increasing transmit frequency, for frequencies above 200 KHz.

Channel-to-Channel Transmit Delay Variability: +/-3 nsec Max

All channels are clocked synchronously from a 250 MHz system clock oscillator that is distributed throughout the system. This specification represents the variation from channel to channel in the propagation delay through the clock distribution path plus the propagation delay variation in the transmit devices themselves.

Transmit Delay Range: 0 to 262 usec

Transmit Delay Resolution: 4 nsec

The per-channel transmit delay is provided by a 16 bit counter operating at 250 MHz, resulting in the range and resolution listed. Transmit delay is independently programmable for every individual channel for every transmit event in the operating sequence, to allow any desired transmit beam focus and steering.

Maximum Imaging Transmit Burst Duration:

In this context, “Imaging” refers to any transmit activity using TPC Profiles 1 through 4 as the source of transmit power. The “Maximum Burst Duration” simply means the threshold beyond which TPC Profile 5 must be used. In earlier Vantage software releases this threshold was very simplistically defined as 25 cycles of the nominal center frequency of the transmit waveform, independent of transmit aperture or voltage level or frequency. A very different threshold has been defined for software releases 3.1 and later: For each individual transmit event the system will estimate the actual transmit burst power level based on the load impedance, burst frequency and duration, size of the transmit aperture, and maximum HV limit being used. If this estimated power level is beyond the capacity of the imaging HV supply for TPC profiles 1-4, the system will either reduce the maximum HV level as needed or exit with an error condition indicating that TPC profile 5 must be used.

Maximum Average Transition Rate 4 MHz

This is the maximum rate (long-term average over the entire event sequence including idle time between bursts) at which the transmit waveform can make transitions from one output state to another. This limit is independent of transmit output voltage or load impedance; it is based on the power dissipation capability of the devices that drive the gates of the transmit FET's. For a continuous periodic waveform for near-CW applications, this limits the maximum transmit frequency to 4 MHz. For a complex arbitrary waveform at a relatively high duty cycle (burst duration / PRI), this will limit the maximum number of individual pulses that can be used to compose the waveform.

3.2 Transmit Output Voltage Control

All transmit channels in the system share the same transmit HV power supply, and thus there is no capability for using different square wave output voltage levels on a per-channel basis within a transmit event. For a repeating periodic output waveform, however, the amplitude of the fundamental component of that waveform can be adjusted on a per-channel basis by varying the relative pulse width (“PWM", or Pulse Width Modulation).

For imaging and Doppler applications, an internal transmit power supply is used. This power supply has been designed to provide a very low level of output noise, and a very high level of stability and repeatability from one transmit event to the next, as required for good Doppler performance.

TPC Profile Selection: Per-PRI Voltage Control

The internal imaging and Doppler transmit supply is also designed to support rapid transitions from one output voltage to another, in between transmit events. This capability is intended to support interleaved operating modes, such as acquiring an ensemble of color Doppler acquisition events at one transmit voltage setting, and then switching to a different transmit voltage for B-mode image data acquisition. The mechanism provided for the user to control this feature is the "TPC Profile".

Up to four TPC Profiles can be defined by the user, each with an independent transmit voltage setting. At any desired point in the T/R event sequence, the user can program the system to switch from one profile to another.

A fifth TPC Profile can also be defined for use with the Extended Burst or HIFU configurations. This Profile disables the internal imaging transmit supply and switches the transmit power to the dedicated HIFU or Extended Burst transmit supply. Use of TPC Profile 5 is not allowed on systems that do not have the Extended Transmit or HIFU configuration options installed.

TPC Profile Voltage Range 1.6 to 96 Volts

Supply voltage delivered to the transmitters can be programmed independently for each of the TPC profiles, to any level within this range.

TPC Profile Voltage Control Continuous, Asynchronous

User GUI controls can be defined to adjust the Voltage setting for each TPC Profile being used, or the voltage can be controlled from any other user-defined function that is invoked during live acquisition. Changing the transmit voltage settings can be done asynchronously, while the T/R acquisition sequence is running without interrupting it. In this case the actual transmit voltage transition will occur between T/R events, never during an event.

TPC Profile Transition Time 0.5 to 15 msec (typical)

The time required to transition from one profile to another will depend on the difference between the two voltage settings, in a manner that is roughly proportional to that difference. A guideline to estimate this transition time in milliseconds is given by the expression $(0.5 + 0.15\ \Delta V)$ where ΔV is the magnitude of the voltage change in Volts. If the user-specified event sequence does not allow enough time for a TPC profile transition, the system will automatically delay the start of the next transmit event long enough to allow the transition to complete.

4. Receive Specifications: Standard, High, and Low Frequency

The specifications in the following receive subsections apply to all of the frequency range configurations of the system, unless they are specifically identified with a particular frequency range. For clarity, all specifications unique to the standard frequency configuration are highlighted in **green text**, specifications unique to the high frequency configuration are highlighted in **blue text**, and specifications unique to low frequency are highlighted in **orange text**. Any specification in black text applies to all three.

Unless noted otherwise, all per-channel receive specifications given here apply to all system configurations: Vantage 256, Vantage 128, Vantage 64LE, and Vantage 64.

Almost all of the functionality of the receive signal path is provided by the AFE5812 integrated TGC preamp and A/D converter device from Texas Instruments. (Note that standard-frequency systems built before approximately September 2015 used the AFE5808A, not the AFE5812.) Refer to the AFE5812 manufacturer's data sheet for more details on some of the features and specifications described briefly in this section. For overall -3 dB bandwidth available through the analog receive path up to the A/D converter, the upper band edge will be set by the choice of anti-alias filter cutoff in the AFE chip. AC coupling at the input to the preamp chip sets the lower band edge -3 dB point. Note also that the user-programmable lowpass and bandpass digital filters after the A/D can be used to tailor the frequency response within this overall analog signal path frequency range.

4.1 Per-Channel Receive Specifications

All specifications apply only to receive signals within the specified "full specification" frequency range and system environmental operating conditions, unless noted otherwise.

Receive Operating Frequency Range

Standard Configuration	**0.5 to 27 MHz**
High Frequency Configuration	**1 to 50 MHz**
Low Frequency Configuration	**50 KHz to 2 MHz**

This is the frequency range over which the receive signal path can provide useful performance. Note however that this range is somewhat broader than the "full specification" frequency range given below. Outside the limits of the full specification range, some aspects of receive performance (such as channel-to-channel uniformity, or variations in frequency response) may degrade, but this degradation is very gradual with frequency.

Full Specification Frequency Range

Standard Configuration	**1 to 15 MHz**
High Frequency Configuration	**4 to 50 MHz**
Low Frequency Configuration	**50 KHz to 1.5 MHz**

Unless noted otherwise, this is the frequency range over which all performance specifications given below are fully met.

Anti-Alias Filter Cutoff: 5, 10, 15, 20, 30, 35, 50 MHz

This programmable third order lowpass filter is built into the AFE chip, prior to the A/D converter. The cutoff frequency is selected automatically by the system based on the frequency response of the transducer being used, but the user can override this setting if desired through use of the Receive Profile structure and associated commands. Note the 5 MHz filter setting is not supported on systems built before September 2015. In addition, standard frequency systems built before that date may not support the 35 and 50 MHz cutoff settings.

TGC Gain Control: 40 dB range

The system generates an analog TGC control voltage that is distributed to all receive preamps. Refer to section 4.4 for details of the TGC control functions.

Channel-to-Channel Gain Variation: +/-1.0 dB max 1 to 15 MHz

This is the worst-case maximum variation between channels over all channels within a system.

Channel-to-Channel Delay Variation TBD nsec

Note at higher frequencies the anti-alias filter is the dominant source of delay variation; this can be minimized by using a higher AAF filter setting and A/D rate, and then bandlimiting and subsampling in the digital signal path.

Receive Input Impedance: Programmable 115 to 3000 Ohms

This is the net input impedance presented by the system at the transducer connector, during receive (while transmit is inactive). The default AFE preamp input impedance is set to 110 Ohms, and there is an additional 8 Ohms from the transmit circuitry which is in series with the preamp input. AFE input impedance can be programmed by the user to change this value if desired. For the High Frequency Configuration, the feedback network used to provide programmable input impedance has been modified to also provide a high-pass function for use with the aliased “4/3 samples per wavelength” A/D sample rate feature. At the lowest impedance setting, this high pass cutoff is at approx. 20 MHz; at higher impedance settings the cutoff moves to progressively lower frequencies and in the high-Z input state the high pass function is disabled, allowing a flat response down to approx. 1 MHz.

Input-Referred Noise Figure 3.2 dB

This is the overall noise figure referred to the transducer connector input, when terminated with a 100 Ohm source resistance and with receive TGC at maximum gain. This noise figure represents the AFE noise performance plus additional noise contributed by system circuitry outside the AFE device. Refer to the AFE data sheet for more details of noise performance as a function of TGC setting, source impedance, frequency, etc.

A/D Converter Sample Rate: 10 MHz to 62.5 MHz
The sample rate is software programmable to any integer submultiple of 250 MHz in the range from 10.0 MHz to 62.5 MHz.

A/D Converter Resolution: 14 bits
See AFE data sheet for linearity and distortion performance, and effective number of bits for the A/D.

Receive Data Buffer Memory: up to approx. 45 Mbytes per channel
This is the temporary buffer in the hardware system, used to store per-channel RF data for subsequent DMA transfer to the host computer. Note that 64 Mbytes of physical memory are available per channel, but part of this memory is used to store descriptor data to program the transmit/receive hardware for each event in the event sequence. Another segment of the memory is used to store precomputed DMA scatter-gather lists defining the address mapping for each DMA transfer of receive data to the host computer. Memory space is allocated as needed for receive data, descriptors, and DMA lists so a script requiring minimal memory space for descriptors and DMA lists could use most of the 64 Mbytes for receive data. For each receive buffer defined in a script, no more than two frames are allocated in the hardware system memory even if a very large number of frames have been defined. Thus the size of the receive buffer stored on the host computer can be much larger than the memory available in the hardware, and is limited only by the amount of memory installed and available on the computer in the Matlab workspace. Since the memory in the hardware system is only used to temporarily store the receive data from the time it is acquired until it has been transferred to the host computer, only two frames are required: one for storing data for the frame currently being acquired, and one for the most recently acquired frame that is now being transferred to the host computer.

Receive data Acquisition Interval Fully Programmable
The acquisition interval for each receive data acquisition event is fully programmable, and is restricted only by the amount of memory available in the hardware system. The start of receive data acquisition can also be delayed by any desired offset from the start of a transmit-receive event.

4.2 Receive Path Parameters: Receive Profile Structure

The AFE preamp-A/D device provides numerous features that are user-programmable through a serial digital control interface. In the Vantage system design, a "Receive Profile" data structure has been defined which the user can add to their setup script, to allow direct control of some of these AFE settings. In addition, event sequence control commands have been defined to allow these settings to be changed at any desired point in the event sequence, such as at the transition from one imaging mode to another. Listed below are the AFE values that can be set through the Receive Profile structure.

- **LNA Gain Control** Selects from one of three choices for the nominal gain through the low-noise input preamp: 15 dB, 18 dB, or 24 dB. Default value is 18 dB if not specified.
- **PGA Gain Control** Selects from one of two choices for the nominal gain through the post-TGC buffer amplifier: 24 dB or 30 dB. Default value is 24 dB if not specified.
- **Anti-Alias Filter Cutoff** Selects one of the cutoff frequency choices: 5, 10, 15, 20, 30, 35 or 50 MHz. If not specified, the system software will automatically select the lowest setting that is above the upper bandwidth limit of the transducer being used.
- **A/D Offset Subtraction Enable** The AFE chip provides a per-channel register which can be subtracted from the A/D sample data, to null out the actual DC offset for that particular A/D. During the system power-up sequence the Vantage system automatically acquires a line of RF data and processes it to determine the DC offset for each channel and write the result to the DC offset subtraction registers. This control variable in the Receive Profile structure simply enables or disables the DC offset subtraction feature; it does not modify the predetermined DC offset values.
- **Input Impedance** Through a programmable active feedback network, the input impedance presented to the transducer can be set over a range from 115 Ohms to several thousand Ohms.
- **Digital High-Pass Filter** At the output of the A/D converter in the preamp-A/D chip prior to outputting the data to the CGD, there is an IIR highpass filter with nine user selectable cutoff frequencies, in roughly one-octave steps from a normalized frequency of 0.0003 to 0.070. This parameter provides 10 choices: one of the nine highpass filter breakpoints or a 10th choice which disables the highpass filter. If this filter is disabled, the low-frequency cutoff of the receive channel will be set by the AC coupling at the input to the preamp-A/D, at 300 KHz.

4.3 RF Data DSP Features

For each receive channel, the Vantage hardware system receives 14 bit RF data from the A/D converter and then applies the following user-programmable DSP functions to this data before writing it to the receive data buffer memory for DMA transfer to the host computer:

Low Pass Filter: A symmetric 23 tap FIR filter is applied to the A/D input data (12 unique coefficients; filter order 22). The LPF coefficients have 16 bit fixed-point resolution, with full scale representing a coefficient value of 1.0. The LPF output summation is 22 bits wide (one MSB extension and 7 LSB extension).

Overflow Detect and Clip: At the 22 bit LPF output, any overflow into the MSB is detected and clipped to full scale, allowing the MSB to be dropped. Three LSB's are truncated, resulting in an 18 bit output representation.

Subsampling: The 18 bit LPF output is then subsampled by a user-programmable factor of 1, 2, 3, 4, 5, 6, 7, or 8.

Bandpass Filter: A symmetric 41 tap FIR filter is applied to the LPF subsampled output data (21 unique coefficients; filter order 40). The BPF coefficients have 16 bit fixed-point resolution, with full scale representing a coefficient value of 1.0. The BPF output summation is 22 bits wide (one MSB extension and 3 LSB extension).

Per-Channel Gain: At the 22 bit BPF output, multiply by a programmable per-channel gain scaling coefficient. This coefficient has 16 bit resolution, with full scale representing a gain of 1.0.

Overflow Detect and Clip: After gain scaling, overflow into the MSB is detected and clipped, allowing the MSB to be dropped. Five LSB's are truncated, resulting in a 16 bit output representation.

Quadrature Bandwidth Subsampling is then applied to the 16 bit BPF output data by one of the following programmable factors:

1 (no subsampling). This results in "4 samples per wave" bandwidth sampling, representing a 200% fractional bandwidth Nyquist limit.

2 ("sample 2 and skip 2"). This results in "2 samples per wave" bandwidth sampling, representing a 100% fractional bandwidth Nyquist limit.

4 ("sample 2 and skip 6"). This results in "1 sample per wave" bandwidth sampling, representing a 50% fractional bandwidth Nyquist limit.

Accumulation and Write to Memory: The bandwidth subsampled output data is then written to buffer memory for DMA transfer to the host computer or if accumulation is enabled, the data is added to previously acquired data read from buffer memory and the result is written back to memory after detecting overflow and clipping at full scale, preserving the 16 bit output width.

RF Data Output Format and Scaling: The RF data samples transferred to the host computer are in a 16 bit, 2's complement fixed point format. With default settings of the DSP processing functions, a full scale value from the A/D converter will come out shifted down one bit to half of full scale in the 16 bit output data sent to the host computer.

Programming the RF Data Processing Functions:

Refer to the Sequence Programming manual for instructions on how to program these functions within an acquisition script.

The quadrature Bandwidth Subsampling Factor is specified by the user, in each individual receive event.

LPF and BPF Coefficients can be specified by the user, in each individual receive event. Or, if the user does not specify the coefficients, the system will automatically select a default filter response based on the operating state of the system. The same set of coefficients is always applied to all receive channels for a particular event.

Per-Channel Gain Scaling Coefficients can be set by the user, independently for each receive event.

Accumulation is programmed by the user on a per-event basis. Any desired number of accumulation events can be applied, before DMA transfer of the resulting data to the host computer. After each new acquisition is summed, overflow detection is performed and any overflow values are clipped at positive or negative full scale of the 16 bit output data.

A/D converter Sample Rate and post-LPF Subsampling Factor are set automatically by the system based on the Receive center frequency specified by the user, to maximize sensitivity and dynamic range. When not using the Verasonics-provided Reconstruction function, the user can set the sample rate to any desired value that is supported by the hardware system.

A/D Clock

In addition to providing the sample clock for the receive channel A/D converters, the A/D clock is the reference clock for setting the duration of the transmit/receive interval, and for all other PRI-related timing functions.

The Receive A/D clock rate is user-programmable as explained above, to any integer submultiple of the 250 MHz system clock over the range 10 to 62.5 MHz (250 MHz clock dividers from 4 to 25).

4.4 Receive TGC (Time - Gain Control)

The system provides TGC Waveform Generation and Control, common to all receive channels as described below. TGC can be programmed through “slide pots” provided as matlab GUI controls by the Verasonics software, or through any other control mechanism implemented by the user.

The TGC waveform is user-programmable as a digital sample sequence driving a D/A converter, with resolution of 512 samples and 10 bits per sample.

The 512 sample TGC waveform spans a maximum interval of 409uS. (800nS temporal resolution or 1.25MHz sample rate).

The system provides a programmable lowpass filter after the D/A converter, to allow the TGC buffer to operate at either ~ 1MHz bandwidth (for rapid transition to a new level between events), or a nominal 50KHz bandwidth (for TGC waveform generation during the receive interval).

If the acquisition interval is longer than 409 usec, the last sample value in the TGC memory is held for the remainder of the interval. A few microseconds before the start of an acquisition interval the D/A output is set to the first sample in TGC memory, so the TGC level can settle to that value before acquisition starts.

Multiple TGC waveforms can be defined, with the desired waveform selected by the Receive structure on a per-event basis.

4.5 Receive Data DMA Transfer to Host Computer

A Receive Data Buffer array is defined in the Matlab workspace on the host computer, when the Verasonics system software is active. This receive buffer is used by the system software processing functions (either provided by Verasonics or written by the user). For live data acquisition from the Vantage hardware unit, Verasonics-supplied software automatically defines and manages DMA transfers of receive data from the buffer memory in the hardware to the Receive Data Buffer in memory on the host computer.

User-Defined Frames The user can specify when in the hardware acquisition sequence a DMA transfer is to take place. Any desired number of acquisition events can be assembled into a receive data frame, for a single DMA transfer of that frame to the host computer (up to the limit of available buffer memory in the hardware system, and a maximum of 2 GBytes in a single DMA).

Simultaneous Acquisition and DMA Transfer After it has been started, the DMA transfer of a frame of data is managed in the background, while the hardware acquisition sequence is free to continue with acquisition of a new frame of data. If the acquisition sequence reaches the point where a new DMA transfer is to be started but a previous DMA is still active, the sequence will automatically pause and wait for the previous DMA to complete (only one DMA transfer can be active at any point in time).

6.6 Gbyte/sec. Typical Maximum Sustained System DMA Transfer Rate (256 channel acquisition, DMA size greater than 64 Mbytes) This data rate is set by the throughput of DMA transfers over the 8 lane, Gen 3 speed PCIe interface to the host computer. This data rate can only be achieved if the host computer's internal transfer rates into main memory can support it. Note also that there is some fixed overhead time associated with starting and finishing a DMA transfer, in addition to the time spent actually moving the data. For DMA sizes smaller than 64 Mbytes, the overhead time becomes significant compared to the data transfer time and thus the maximum DMA transfer rate that can be achieved will be reduced. With 256 channels active the maximum per-channel data transfer rate will be restricted to approximately 27 Mbytes/second.

4.9 Gbyte/sec. Typical Maximum Sustained System DMA Transfer Rate (128 channel acquisition, DMA size greater than 64 Mbytes) With 128 (or fewer) channels active, the maximum data rate individual channels can achieve becomes more restrictive than the shared PCIe interface to the host computer, so the total data rate drops below 6.6 Gbyte/sec. In this case, the maximum transfer rate is set by the approximately 39 Mbyte/sec. maximum limit of each channel. To achieve this rate the total DMA size must still be kept above 64 Mbytes to reduce the overhead time to an insignificant level.

5. Per-PRI Event Sequence Timing and Control

Transmit-Receive Relative Timing: Transmit and Receive timing for a transmit-receive event start simultaneously, i.e. the beginning of the transmit delay interval coincides with the beginning of the active receive interval. As a result, receive data acquisition can be active throughout the transmit interval.

Transmit-Only Event: A transmit event can be executed with no receive activity at all. All other aspects of the transmit event timing, software control, and performance remain unchanged.

Transmit Event Duration is set by the sum of the longest transmit delay over all active transmit channels, plus the transmit burst duration for that channel.

Receive-Only Event: A receive event can be executed with no transmit activity at all. All other aspects of the receive event timing, software control, and performance remain unchanged.

Receive Event Duration is set by the duration of the active receive interval that has been programmed for that event (round-trip propagation time to the distance specified by Receive.endDepth).

Event Overhead Time: The total time required to complete a transmit-receive event is the maximum of (Transmit Event Duration or Receive Event Duration) plus an overhead time. The overhead time is required to program the hardware in preparation for the next event, flush the receive data pipeline, etc. and is typically 2 to 5 microseconds. This overhead time will increase substantially if any of the following items are included in the event (note that if more than one of the following functions is included in an event, they are usually executed concurrently and thus the overhead time increase will be set by the slowest added function):

- HV mux programming for a transducer with HVmux element switching
- TPC profile transition before the next event
- Receive Profile transition before the next event
- Receive A/D sample rate change from the last event
- TGC settling time to the initial value for the next event

Event PRI Control with "timeToNextAcq" Command: The total PRI time for a transmit-receive event can be programmed by the user using this command, to any desired value that is greater than the actual event duration plus overhead (or an absolute minimum of 10 usec), and less than 4.19 seconds. The desired time must be specified as an integer number of microseconds. If a T-R event does not include a timeToNextAcq command, then the following event will start as soon as the current event duration plus overhead time for the next event are completed.

Trigger Input Control: Any transmit-receive event can be programmed to pause and wait for a trigger input signal to be detected on one or both of the rear panel trigger input connectors, before starting execution of the event.

Pause for DMA Completion: At any desired point in the acquisition sequence, a "transferToHost" DMA command can be inserted which will initiate the DMA transfer of previously acquired receive data up to the host computer. Normally this DMA transfer occurs in the background, while the hardware event sequence continues with execution of subsequent T-R events. But if the sequence reaches another DMA transfer command before a previous DMA transfer has been completed, the hardware acquisition sequence will pause and wait for the DMA to finish. Then it will launch the new DMA and resume execution of the event sequence.

Pause for hardware-software Synchronization: When the Vantage system is running, there are actually two separate event sequencers in operation: a hardware event sequence running in the Vantage hardware unit that executes transmit-receive acquisition events and initiates the associated DMA transfers, and a software event sequence running in the host computer that executes all of the software-based signal processing, image processing, and image display functions. In some cases these two sequencers are allowed to proceed asynchronously from each other but when desired a "sync" command can be included in the event sequence. When either sequencer reaches a sync command, it will pause at that point and wait for a handshake signal that indicates the other sequencer has reached the same point. Then both sequencers will continue from there at the same time. So if the events in the software sequence took longer to execute than those in the hardware sequence, the hardware sequencer would pause when it encountered a sync command and wait for the software sequence to catch up.

External Trigger Inputs and Synchronization: Refer to section 9.2 for details of the system trigger in and trigger out capability and synchronization clock signals for use with external devices or for synchronizing multiple Vantage systems.

6. Probe Connector Interface & Functionality

For Vantage systems configured with the UTA feature, multiple UTA modules are available supporting different connector types (see section 1.3 of this document for a summary). In addition to the transmit/receive transducer element signals, the system provides the following additional probe-related features through additional signal pins at the connector. Note however that some UTA modules do not support all of these features; refer to the documentation for a specific UTA module to see which features it provides as well as detailed interface specifications for those features.

Probe Connect / Disconnect Sensing is provided through nearly all probe connectors by monitoring for a DC path to ground through one of the connector pins that is nominally defined as a ground pin. When a probe is connected, it will tie all ground pins together and thus provide the DC ground path for the connect sense pin. On the system side this pin still serves as an RF ground since it is shunted to ground through a capacitor.

Probe ID Support: The system provides DC power and control/data signals allow read/write access to a serial ID EEPROM located within the probe. Vantage system software can interpret the ID data, and automatically provide programming parameters for transducers that are “known” by the system. For commercial probe families that do not include a serial ID EEPROM, the associated UTA module may provide an interface for reading probe ID jumpers or other ID schemes and translating this into an ID code that can be interpreted by the Vantage software.

Support for transducers equipped with HV Mux devices: The system provides the following features.

- DC power supplies with programmable levels, to meet the needs of different types of HV Mux devices (Positive and Negative HV bias supplies and a lower voltage logic-level supply).
- Mux programming data, clock, and control signals with programmable levels, data rates, and timing to meet the needs of different types of HV mux devices.
- Programmable mechanisms to limit the maximum transmit output level as needed to protect a particular transducer/HV mux from damage.
- Software utilities to allow programming of the HVMux switches for each transmit-receive event in an acquisition sequence.

Support for transducer temperature monitoring, for transducers with internal temperature sensing thermistors.

Note that the Vantage system does not provide support for mechanically scanned transducers (motor drive capability and position sensors).

7. Diagnostics, Self-Test, Configuration Management

These functions are implemented primarily through software access to hardware.

7.1 System Verification Test Utility

This is a software utility provided with the system that can be invoked by the user whenever desired, by typing “VersonicsVerificationTest” (or equivalently, just “VVT”) at the Matlab command prompt. This utility performs an exhaustive and fully automated self-test of all system hardware features including the transmit-receive performance of every channel within the system, using some of the self-test features described in the following sub-paragraphs.

Transmit-Receive Channel Test BIST Network

Internal to each acquisition module (containing 64 transmit-receive channels) a transmit-receive BIST (Built In Self Test) loopback network has been provided, to allow thorough self-test of all transmit and receive functionality on a per-channel basis with no external test fixtures or test equipment required.

This network consists of a large resistor connected from each transmit-receive channel on the board to a common node terminated with a relatively low impedance to ground. As a result, when a transmit channel is exercised with nothing connected at the transducer connector a highly attenuated version of the transmit signal is presented to neighboring receive channels. The attenuation through this network is high enough that it makes a negligible contribution to channel-to-channel crosstalk when a transducer is actually connected to the system.

This BIST network is used extensively by the software test utilities provided by Verasonics, but the system software also provides mechanisms for a user to access this network to support user-developed self test or transducer test functions.

7.2 Hardware Module Configuration Management

Each of the major hardware modules (printed circuit board assemblies) within the Vantage system includes an EEPROM that is programmed during the manufacturing process with the name, part number and revision level, serial number, date of manufacture, and other pertinent information for that particular assembly. software utilities are provided with the system to interrogate these EEPROM's and display their contents. The run-time software also checks these EEPROMs at each system power-up cycle, to verify the system hardware configuration is compatible with the optional features that have been installed on the system.

7.3 Internal Temperature Sensors

Within the Vantage system hardware chassis, those hardware modules with a significant level of power dissipation have been equipped with built-in temperature sensors located within or near the most heat-sensitive components. During normal operation, the system continuously monitors these sensors and will report warning and error conditions to the user when predetermined safe operating temperature limits have been exceeded. In response to an over-temperature error condition the system will automatically shut down.

7.4 Front Panel LED Status Indicators

The system provides four externally visible front-panel status indicators, which can be user-programmed to represent the state of selected event sequence timing or control signals. Refer to the User Manual for information on programming the status indicators

Default Display: If the user has not specified a status LED mapping in the setup script, the system software will by default display the following four status signals through the four LED's:

1. (Leftmost LED): hardware Event Sequence is running
2. On when hardware sequence is running but has paused.
3. On during the active acquisition interval within a transmit/receive event.
4. (Rightmost LED): On when receive data DMA transfer to host computer is active.

8. External Interfaces to the System

8.1 PCI-Express Host Computer Link and Adapter

A single x8, Gen 3 PCI-express interface provides the bi-directional communication path between the Vantage subsystem and the host computer. This interface originates at a PLX PCIe switch device inside the system. From there, it is routed through the rear panel connector to a PCIe extension cable assembly going to a similar connector on the external I/O panel of the host computer adapter module. The host computer adapter routes the PCIe signals from the cable connector through another PCIe switch device to the expansion slot within the host computer. For full performance the host computer must provide either 8 lanes at Gen 3 speed or 16 lanes at Gen 2 speed at the expansion slot used by the host computer adapter module.

The host adapter card and the 1 meter PCIe cable assembly are provided by Verasonics along with the Vantage hardware system.

8.2 External Trigger and Clock Signals

Trig_Out A dedicated BNC connector is provided on the Rear I/O panel for this signal. This is a 3.3 V. TTL-compatible output signal, generated by the ASC FPGA. When enabled by a user's setup script for a particular transmit/receive event in the event sequence, Trig_Out provides a 1 usec. active-high pulse at the same time as the beginning of the acquisition interval for that event (the starting point for the transmit delay programmed on each transmit channel, and the beginning of the receive data acquisition interval).

Trig_In_1, Trig_In_2 Two additional dedicated BNC connectors are provided on the Rear I/O panel for these two trigger input signals. When enabled by a user's setup script for a particular transmit/receive event in the event sequence, the trigger input signals can be used to synchronize the start of an acquisition T/R event to an external device. These are 5 V. tolerant, TTL-compatible input signals; they must not be driven below ground or above +5.0 Volts. The trigger input signals are re-clocked to the the system's internal even sequence synchronization clock, running at 1/4 of the sample clock rate that has been programmed for the A/D converter (10 to 62.5 MHz). Thus if the source of the Trig_in signal is asynchronous to the system, there will be an uncertainty of one sync clock period in the system's response to the trigger input.

Clock Signals

Clock I/O These connectors provide four differential pairs supporting the clock signals as defined below.

250M_In: A 250 MHz clock input signal, which under software control can be selected as the source for the system's 250 MHz master clock in place of the internal crystal oscillator. This input can be used to synchronize the system clock to an external device or another Vantage system. Note however that the clock signal provided by the external device must be within 100 ppm of the nominal 250.0 MHz, to ensure proper system operation.

250M_Out: A 250 MHz clock output signal, which can be used to synchronize an external device (or another Vantage system) to the system's internal 250 MHz master oscillator.

SYNC_CLK_OUT: A synchronizing clock output signal. When the system is to be triggered by an external device using one of the Trigger inputs, this clock output can be used to synchronize the external device to the system's internal sequencer clock, allowing jitter-free triggering of the system.

SYNC_CLK_IN: When the system is to be synchronized to an external device supplying the 250M_In master oscillator signal, this signal must also be driven by the external device, to synchronize the phase of the internally generated system clocks (at submultiples of 250 MHz) to the external device.

8.3 AC Line Power Input

There is an IEC connector module located at the back of the system, for use with a detachable power cord. This module also provides an AC line disconnect switch and fuse. From this module, the AC line power is routed directly to the OEM 12 Volt power supply mounted within the system.

The OEM supply provides universal AC line input capability: 100 - 240 V., 50 - 60 Hz.

Typical Vantage Unit Power Consumption

5 Watts or less: System in shutdown state (Vantage system is powered down, but the internal OEM AC power supply is in its standby operating state, ready to power up the system under control of the host computer).

200 Watts: Vantage 256 system powered up and initialized, in an idle state with no transmit-receive activity.

280 Watts: Vantage 256 system in a typical operating state running an imaging script.

500 Watts: Vantage 256 system in a worst case therapeutic HIFU transmit operating state (External HIFU Configuration only), near-CW transmit activity with all 256 transmit channels active.

Note that these power consumption estimates apply only to the Vantage unit and do not include power consumed by the host computer, display monitor or other peripheral devices, or the external HIFU transmit power supply in the case of the HIFU system configuration.

AC Line Isolation, Emissions, Susceptibility

The OEM 12 Volt power supply provides a 'medical grade' AC line input capability in terms of leakage current and other regulatory requirements.

The only devices in the Vantage unit with any connection or proximity to the AC line are the OEM power supply, and the IEC connector module at the rear of the system. For details of the regulatory/safety characteristics of the AC line input, refer directly to the manufacturer's specifications and data sheets for these two devices.

OEM Power Supply: TDK/Lambda CSS500-12

IEC Connector module: TE Connectivity PE0S0DHXB

8.4 External HIFU Power Supply Input

For systems configured with the HIFU Configuration, this 4-pin high current connector provides the input power connection from the external HIFU transmit power supply. For all other system configurations this connector should be left open. The cable for connecting the external power supply to the system is provided by Verasonics for systems with the HIFU configuration.

For a system with the HIFU Configuration, Verasonics also provides the external power supply itself, AIM-TTI model QPX600DP. This is a commercial bench power supply providing a software-programmable DC output voltage and current, at power levels up to 1200 Watts. System control of the power supply is through a USB cable connection directly from the supply to the host computer for the system. The power supply has its own separate AC line power cord and connection.

9. Mechanical and Environmental Specifications

9.1 Size and Weight

Vantage Chassis Overall Size:

19.25 inches (48.9 cm) high (includes rubber feet at bottom of chassis extending approx 0.4 in./ 1.1 cm)

11.0 inches (28.0 cm) wide

18.75 inches (47.6 cm) deep

At least 4 inches (10 cm) of clearance is required at the rear of the chassis to allow for the PCIe cable and connector. Minimum allowed bend radius for this cable is 1.5 inches (3.8 cm).

Unobstructed access is required to the front of the chassis to allow for the transducer connector(s) and cables and for cooling air intake at the bottom front.

System Weight (Vantage chassis assembly by itself):

35.6 lb (16.1 kg) 128 channel (2 acquisition boards) configuration

42.0 lb (19.1 kg) 256 channel (4 acquisition boards) configuration

55.6 lb (25.2 kg) 256 channel (4 acquisition boards) with HIFU configuration installed

9.2 Environmental Requirements

Operating Temperature Range: 10 to 40 degrees C. (50 to 104 deg. F.)

Shock & vibration, altitude, humidity: Generally speaking, the Vantage system is designed for use in an indoor laboratory environment. It cannot be expected to operate reliably in outdoor, industrial, or mobile environments.

System must be mounted in a vertical position, both during use and in transport.

See section 9.4 for AC line power input requirements

9.3 Cooling

The Vantage unit includes a self-contained forced-air cooling system. Air intake is through holes near the bottom of the front cover, bottom front of both sides, and through the front half of the bottom of the chassis. Air exhaust is near the top at the rear of the system. The system automatically adjusts the fan speed based on temperature sensors embedded within the system. If internal temperatures exceed predefined limits, the system will issue warnings to the user at a warning temperature threshold, and automatically shutdown at a shutdown temperature threshold. These thresholds are set by Verasonics based on the system configuration and expected operating environmental conditions; they are not user adjustable.

The system must be positioned and mounted such that the air intakes have unimpeded access to fresh room-temperature air, not air that has been preheated by other devices.

Air exhaust outlets must also have an open, unimpeded path to free air in the room with minimal back pressure. If the Vantage unit is mounted in an enclosure, care must be take to ensure that heated exhaust air will not be drawn back into the air intake openings.

9.4 EMI, EMC, and Regulatory/Safety

Vantage systems built after September 2015 have CE, UL, and CSA approval to the regulatory and safety standards for use as laboratory test equipment (Standards IEC 61010-1 3rd Edition (2010) and EN 61010-1:2010 3rd Edition, UL 61010-1: 2012, and CAN/CSA-22.2 No. 61010-1-12). This approval covers all applicable regulatory requirements for emissions, susceptibility, and safety hazards.

The Vantage system does not have regulatory approval for use as a diagnostic device on human subjects, however. It is the customer's responsibility to undertake the required levels of testing and regulatory reviews, before using the system as an investigational device on human subjects or as a component of a commercial medical product. Refer to the document “Verasonics Safety Guidelines for Imaging Human Subjects” (included in the documentation package with all Vantage software releases) for guidance on the steps required for IRB or similar approval.

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