

## RF Data Acquisition in the Verasonics Research Systems

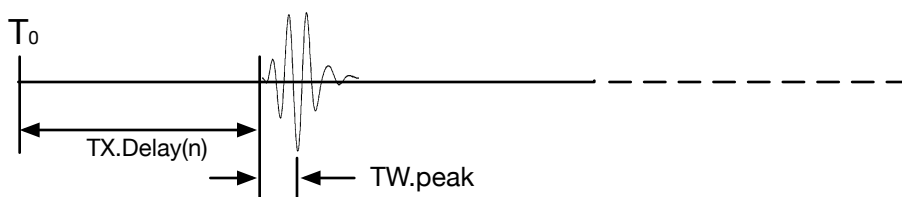
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### 1. Introduction

This document provides timing details of the data acquisition process in the Verasonics V1 and Vantage Research Ultrasound Systems. This information should prove useful for those who want to do their own signal processing and image reconstruction. In the discussion below, the term 'wavelength' always refers to the wavelength of the center frequency of the transducer,  $f_c$ , which is given by the speed of sound,  $c$ , divided by  $f_c$ . Wavelengths are often used to specify a time period; for example, a transmit delay of 10 wavelengths is equivalent to a time period of  $10/f_c$ .

### 2. Transmit/Receive Timing

All transmit and receive actions start from a common time reference,  $T_0$ . For transmit, a delay counter is started at  $T_0$ , and counts at the master clock frequency,  $f_0$  (180MHz for V1, 250MHz for Vantage). The counter counts down the value specified in  $\text{TX}(n).\text{Delay}(m)$ , where  $n$  is the index of the transmit structure and  $m$  is number of the transmitting element in the aperture. This delay, which is specified in wavelengths of the Transducer center frequency,  $f_c$ , is converted to a number of counts of the master clock,  $f_0$ , which is used to program the delay counter. At the end of the count, the transmit waveform is generated.



The  $\text{TW.peak}$  parameter specifies the time (in wavelengths) from the start of the transmit waveform to the time of peak energy.  $\text{TW.peak}$  is computed by the `computeTWWaveform` utility function from the envelope of the simulated TW waveform. This value, when added to the  $\text{TX.Delay}(n)$  value, gives the effective time that the transmit waveform leaves the surface of the array element  $n$ .

On receive, all channels start their sampling at time  $T_0$ , and continue sampling at a constant rate through the end of the acquisition period. The sampling period therefore includes the transmit waveform, although the receiver inputs during transmit are saturated by the large transmit voltage swings. The target sampling rate for RF data is  $4 \cdot f_c$ , but since the sample clock must be derived from the master clock, the actual sample frequency may differ slightly from  $4 \cdot f_c$  if it does not divide equally into  $f_0$ . In addition, if it is possible to sample at a higher multiple of  $f_c$  and then by filtering and decimation reduce the rate to  $4 \cdot f_c$ , this choice is made to more adequately sample and filter out system noise. Ultimately, the sample rate for 200% bandwidth RF data in the Receive Buffer is specified by the Receive attributes `Receive.VDASADRate` and `Receive.VDASFilter` using the following formula:

$$\text{RcvBufferSmpIRate} = (f_0 / \text{Receive.VDASADRate}) / \text{Receive.VDASFilter}$$

These attributes can be used for both Vantage and V1 systems as they are derived by the system from the user specified attributes. They can be obtained from the Matlab workspace after processing a sequence programming script with the loader program VSX.

One must pay attention to a possible difference between the sample frequency and four times the center frequency of the transducer,  $f_c$ , especially in software releases after version 3.0. In prior releases, Trans.frequency was set to a 'realizable' frequency, based on the master frequency clock, leading to a precise four times relationship with the sample frequency. With the 3.0 release, the Trans.frequency is set according to the transducer specification alone, and the  $4*f_c$  sampling frequency is chosen as the nearest realizable rate. This leads to non-integer Receive.samplesPerWave values such as 3.95 rather than 4.0. The  $f_c$  center frequency wavelengths value is still used as a measure of length and time.

### **3. Factors to Consider in Image Reconstruction**

#### **3.1 Lens Correction**

A factor that must be taken into account when performing image reconstruction is the different speed of sound through the acoustic lens on the face of the transducer. For almost all transducers, the speed of sound in the lens is lower than the speed of sound in tissue. Thus, the lens adds an additional travel time, or path length to the ultrasound's round trip path. This extra path length is approximated by a single wavelength value in Trans.lensCorrection, which represents the average one way apparent extra path length for travel through the lens. The Trans.lensCorrection value is provided by the computeTrans.m utility function for transducers known by Verasonics.

#### **3.2 Element Sensitivity**

In the image reconstruction process, the spatial sensitivity of individual transducer elements (often referred to as directivity) must be taken into account. This can be specified as a function of angle,  $\alpha$ , from the normal to a transducer element, where  $\alpha$  ranges from  $-\pi/2$  to  $\pi/2$ . This function is provided by the computeTrans.m utility in the Trans structure with the array Trans.ElementSens. The index of this array ranges from 1 to 101, representing angles at increments of .0314 radians between  $-\pi/2$  and  $\pi/2$ , with an index of 51 specifying the normalized sensitivity value of 1.0 for an angle of zero radians. The Trans.ElementSens array can be used to determine if an element can adequately 'see' the reconstruction point. If the absolute angle between the element's normal and the line connecting the element's center to the reconstruction point is greater than that specified by a sensitivity cutoff value (Recon.senscutoff), the element can be eliminated from the reconstruction aperture.