Application of AlazarTech PCI/PCIe Digitizer on Optical Coherence Tomography （OCT）

AlazarTech PCI/PCIe 高速数据采集卡在光学相干断层扫描（OCT）的应用

（以英文原文为准，中文翻译仅供参考）

金朗科技（香港）有限公司

(中国内地：深圳市金朗科技有限公司)

广东省深圳市南山区高新技术产业园区

高新南一道 009 中国科技开发院孵化楼 309

Phone: +86-755-26995658

Email: goldfire@139.com

QQ: 841655201

Scott Engineering Limited

309,FuHua Building,

China Academy of Science and Technology Development,

009，First High-Tech South St.，NanShan District

ShenZhen, GuangDong, PR China

Application Note: 应用案例：

Contents 目录

Introduction 引言

In the last decade, Optical Coherence Tomography has emerged as an important diagnostic and research tool in several medical fields, including ophthalmology, cardiology, and neurology. OCT is unique as a non-contact, non-invasive imaging modality that can acquire sub-surface high-resolution cross sectional images of biological tissue [1].

近十年来，光学相干断层扫描技术（OCT）已成为一种重要的医疗诊断与研究工具，应用于多个医疗领域，包括眼科、心脏科、神经科等。OCT 是一种非接触式的无创成像模式，它的独特之处是能够采集生物组织次表层高分辨率的截面图像。[1]。

Wavelength Swept Source (SS) OCT implementations dominate in longer wavelength regions, particularly at 1310nm where there are an abundance of fiber optic components from the telecommunications industry. Light at this wavelength penetrates deeper in tissue than shorter wavelengths, but suffers from high water absorption. Applications of high speed OCT imaging in this wavelength range include: ocular anterior chamber, early cancer detection, cardiovascular imaging, and visualization of early developmental biology [2].

波长扫频光源（SS）OCT 实施的优势在于拥有较长的波长区，特别是在波长为 1310nm 时，存在电信行业提供的大量光纤组件。与较短的波长相比，该优势变的尤为突出，因为波长为该值的光，它的穿透组织能力更强，深度更深，但是吸水率相对较高。在该波长范围内，高速 OCT 成像的应用领域包括：眼前房、早期癌症检测、心血管成像、早期发育生物学可视化等[2]。

In this application note, the basics of OCT imaging are described from the perspective of wavelength swept imaging. A typical implementation of an externally clocked SS OCT system is introduced, and schematically illustrated. The features on AlazarTech waveform digitizers specifically suited for SS OCT signal acquisition are described, enabling high speed, high performance imaging.

在本应用案例中，我们从波长扫频成像的角度说明 OCT 成像的基础。我们介绍了实施外部时钟 SS OCT 系统的一种典型案例，并给出了图解说明。同时，对于特别适用于 SS OCT 信号采集的 AlazarTech 数据采集卡，我们还详细描述了这些产品的特征，从而实现高速、高性能的成像应用。

Optical Coherence Tomography 光学相干断层扫描

Medical imaging with OCT is described as an optical analog to Ultrasound. Axial cross sectional data (called A-scans) are generated by the interference of light backscattered from a sample with light reflected from a reference. A sequence of A-scans acquired while transversly scanning the beam is called a Brightness (B)-scan. Volumetric images can be constructed by sequentially acquiring cross-sectional images generated through raster scanning, usually using galvanometer scanning mirrors. A simplified version of an OCT system using a fiber-based Michelson interferometer-type configuration is illustrated in Figure 1.

使用 OCT 进行的医学成像，原理类似于超声成像，只是用光波代替了声波。样品的后向散射光的干涉生成轴向截面数据（称作 A 扫描），同时伴随从参考臂反射而来的光。横向扫描光束时获取的 A 扫描序列被称为亮度扫描（B 扫描）。通常，通过连续采集光栅扫描生成的截面图像，我们可以使用光学扫描振镜进行立体图像构建构成。图 1 是 OCT 系统的一个简化形式，该系统使用光纤迈克耳逊干涉仪类型的配置。

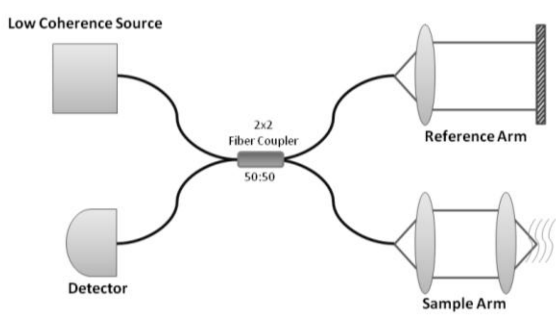


Figure 1: Simplified OCT using a fiber-based Michelson interferometer type configuration

图 1：使用光纤迈克耳逊干涉仪类型配置的简化 OCT 系统

Low Coherence Source：低相干光源

Detector： 检测器

Fiber Coupler：光纤耦合器

Reference Arm： 参考臂

Sample Arm：样品臂

Light backscattered from the sample and reference arms are recombined in the fiber coupler and interfere to produce fringes related to the optical path length difference. Using a low-coherence light source with a spectrum, *S(k)*, the light returned from the reference and sample arms, I_R and I_S, with a path length mismatch of Δz, the signal acquired at the detector can be represented by

样品臂和参考臂的后向散射光在光纤耦合器中重新结合，并进行干涉，以产生与光程差相关的干涉条纹。探测器采集的信号可以由下式表示，其中，*S(k)*表示低相干光源光谱，I_R 和 I_S 分别表示从参考臂和样品臂折回的光，Δz 表示光程失配。

$$I_{det}(k) = S(k)\left(I_R + I_S + 2\sqrt{I_R I_S}\cos(2\Delta z k)\right). \qquad (1)$$

The source spectrum, *S(k),* is related by the Fourier transform to *S(Δz)*, which represents the Point Spread Function (PSF) or axial resolution of the system. Assuming a Gaussian profile having a full width half maximum (FWHM) spectral bandwidth $\Delta\lambda$, the width of the PSF is given by [3] [4]

傅立叶变换将光源 *S(k)*与 *S(Δz)*联系起来，表示系统的点扩散函数（PSF）或轴向分辨率。假设高斯分布图具有半峰全宽（FWHM）的光谱带宽 $\Delta\lambda$，PSF 的宽度可以通过以下公式计算得出[3] [4]。

$$l_c = \frac{2(ln2)}{\pi}\frac{\lambda^2}{\Delta\lambda}, \qquad (2)$$

where λ is the central wavelength and $\Delta\lambda$ is the source bandwidth in wavelength units. In this form, the resolution can be seen to depend not only on the bandwidth of the source, but also on the central wavelength. This implicitly indicates that in OCT, the axial resolution is de-coupled from the transverse resolution, which is dependent on the sample arm imaging optics.

其中，λ表示中心波长，$\Delta\lambda$表示光谱宽度。在该式中，我们可以发现，分辨率不仅取决于光谱宽度，而且还依赖于中心波长。这暗示了在 OCT 中，轴向分辨率从横向分辨率开始解耦，该过程依赖于样品臂的成像光学技术。

Fourier Domain OCT 傅立叶域 OCT

Fourier domain (FD) detection in OCT has gained much attention due to the increased sensitivity and acquisition speed compared to the original method, time domain (TD) OCT. FD OCT uses a stationary reference arm reflector, and the optical path length difference of scatterers in the sample arm relative to the position of the reference arm is encoded by the frequency of the interferometric fringes as a function of the source spectrum, *S(k)*. In FD OCT, acquiring the optical spectrum of back-reflected light at permits all depths to be acquired simultaneously rather than sequentially. The signal acquired at the detector is a function of the wavenumber given by Equation (1), simplified for the case of a single reflector in the sample. The location of the reflector in the sample can be extracted by taking the Fourier transform of Equation (1) to obtain

与传统时域（TD）OCT 技术方法相比，OCT 中的傅立叶域（FD）检测具有更高的灵敏度和采集速度，因而有着广阔的应用前景。FD OCT 使用固定的参考臂反射器，与参考臂位置相对的样品臂中的散射体光程差由干涉条纹频率进行编码，作为光源光谱函数 *S(k)*。在 FD OCT 中，后向反射光光谱的采集允许所有深度的光信号同时采集，而不用按顺序进行采集。检测器采集的信号是

式（1）所示波数的一个函数，针对样品中为单反射器的情况，我们对此类信号进行了简化。我们可以采用公式（1）的傅立叶变换，来获知样品中反射器的位置。

$$\mathcal{F}^{-1}\{I_{det}\} \propto \hat{S}(z) \otimes \left((I_R + I_S)\delta(z) + 2\sqrt{I_R I_S}\left(\delta(z+\Delta z) + \delta(z-\Delta z)\right)\right), \tag{3}$$

where the first term on the right hand side is the Fourier transform of the source. The first term in the parenthesis is the DC term, and corresponds to the DC spectrum, and the second term in the parenthesis represents the location of the reflector and its complex conjugate. Complex conjugate artifacts arise because, generally, OCT systems do not acquire the phase of the interferometric signal. Various techniques have been investigated to resolve this problem during imaging, effectively doubling the imaging depth of the system.

其中，右边的首项为光源的傅立叶变换。括号中的首项为 DC 项，与 DC 光谱相对应；括号中的第二项表示反射器的位置及其复共轭。一般来说，由于 OCT 系统不采集干涉信号的相位，因而出现了复共轭效应；为了解决成像过程中出现的这一问题，我们已经对各种技术进行了研究，从而使系统的成像深度有效地加倍。

For OCT systems, the maximum sensitivity is determined by the shot noise limit of the system. Typically, the reference arm reflectivity is much higher than the sample arm, where excess photon noise will dominate. However, largely attenuating the references arm will cause receiver noise to dominate. Accordingly, to achieve maximum sensitivity, the reference arm power has to be adjusted to a reflectivity in between the two cases. Consequently, the maximum sensitivity is a function of the reflectivity of the sample R_s, power incident on the sample P_s and electronic charge e [5]. For SD OCT, the Signal to Noise Ratio (SNR) is given by [3]

就 OCT 系统而言，最大灵敏度由系统的散粒噪声限制决定。通常，参考臂的反射率比样品臂高得多，在这种情况下，过量光子噪声占支配地位。然而，大幅度削弱参考臂会导致接收机噪声占支配地位。相应地，为了达到最大灵敏度，就必须将参考臂功率调整到介于两种情况之间的反射率。因此得出，最大灵敏度是样品反射率的一个函数 R_s，样品的入射功率用 P_s 表示，电子电荷用 e 表示 [5]。对于 SD OCT，信噪比（SNR）可以根据以下公式计算得出 [3]。

$$SNR_{sdoct} = \frac{R_S P_S \Delta t}{2e}, \tag{4}$$

where Δt is the line integration time. Equation (5) shows that the SNR is not dependent on the detection bandwidth (as was the case with Time Domain OCT) but proportional to integration time.

其中，Δt 表示线积分时间。式（5）表明信噪比不是取决于检测带宽（在时域 OCT 中，信噪比由检测带宽决定），而是与积分时间成一定比例。

The sensitivity advantages obtained through spectrally resolved detection, state-of-the-art FD OCT systems permit operation at line rates in the hundreds of kilohertz with image quality superior to older, slower systems. Two types of FD OCT are widely used in research, and are differentiated based on the combination of the source and detector used. Spectral Domain (SD) OCT (also called S OCT) uses a low coherence broadband light source and a spectrometer which uses a diffraction grating to disperse the interferometric signal spectrum across a linear array detector. Swept Source (SS) OCT uses a wavelength swept laser source and photodiode balanced receiver as the detector. Whereas SD OCT spatially encodes spectrally resolved interference signal, SS OCT time-encodes the spectral signal as the narrow laser linewidth sweeps through a broad spectrum [6]. Although the detected signal is acquired in a different manner, the interpretation is the same, i.e. the frequency of the interferometric fringes corresponds to the location of the sample scatterer. The system level advantages of SS OCT over SD OCT are evidenced through the differences in signal acquisition. SS OCT systems can be designed with faster line rates and longer imaging depths than possible with the spectrometer based systems.

先进的 FD OCT 系统通过光谱分辨检测获得了灵敏度优势，允许在数百千赫兹的频率范围内以线速进行操作，图像质量高于较旧、较慢的系统。FD OCT 的两种类型广泛应用于研究领域，这两种类型根据光源和使用的检测器进行区分。谱域（SD）OCT（也称为 S OCT）采用低相干宽带光源和分光计，该分光计使用衍射光栅来分散线性阵列检测器上的干涉信号频谱。扫频光源（SS）OCT 使用波长扫频激光器光源，并使用平衡式光电二极管接收机作为检测器。尽管 SD OCT 对光谱分辨率干涉信号进行了空间编码，但是随着窄线宽激光横扫广谱，SS OCT 还对光谱信号进行了时间编码[6]。虽然以不同的方式采集检测到的信号，但是判读方法却是相同的，即干涉条纹的频率与样品散射体的位置相对应。信号采集中呈现的差异清楚地表明：在系统层级方面，SS OCT 比 SD OCT 更具优势。与基于分光计的系统相比，SS OCT 系统的设计可以具备更快的线速以及更深的成像深度。

Swept Source OCT 扫频光源OCT

There many configurations for implementing a wavelength swept laser for SS OCT, but the principle components are a gain medium and a tunable wavelength filter designed in a feedback configuration as shown in Figure 2.

用于 SS OCT 的波长扫频激光器有多种配置可选，但是主要组件为增益介质和波长可调谐滤波器，在反馈 配置中设计了这两个组件，如图 2 所示。

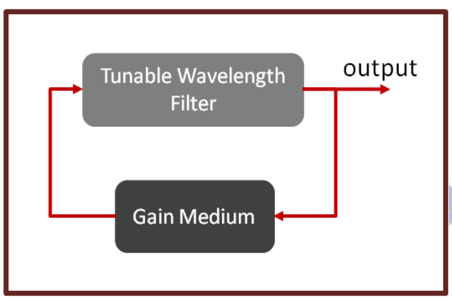


Figure 2: Conceptual wavelength swept laser configuration

图 2：波长扫频激光器概念性配置

Tunable Wavelength Filter：波长可调谐滤波器

Gain Medium：增益介质

Output：输出

A typical SS OCT system (Figure 3) consists of a wavelength swept laser, an optical circulator, a balanced photodiode detector and a high-speed waveform digitizer configured into an interferometric topology.

典型的 SS OCT 系统（图 3）包括：波长扫频激光器、光环行器、平衡式光电二极管检测器，以及配置在干涉拓扑结构中的高速数据采集卡。

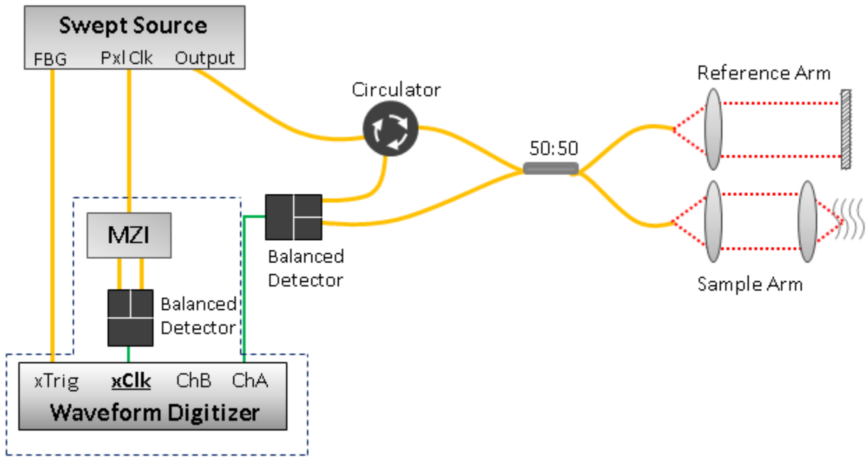


Figure 3: Swept source interferometric topology

图 3：扫频光源干涉拓扑结构

Swept Source：扫频光源

Output：输出

Circulator：环行器

Balanced detector：平衡式检测器

Waveform digitizer：数据采集卡

Reference arm：参考臂

Sample arm：样品臂

Light from the laser goes through the optical circulator, and is divided into the sample and reference arm by the fiber coupler. The backreflected light in the reference and sample arm is recombined by the coupler. The detector arm of the interferometer is directed to one input of a balanced photodiode detector. The light travelling backward through the source arm is recovered by the circulator and delivered to the other input of the balanced photodectector [5]. Balanced detection provides better sensitivity over a single detector because it rejects common mode noise and is more efficient in light usage. The resulting interferometric signal has an ac-coupled appearance.

激光器发出的光通过光环行器，被光纤耦合器分成样品臂和参考臂。耦合器将参考臂和样品臂的后向反射光重新结合。干涉仪的检测器臂指向平衡式光电二极管检测器的一个输入端。环行器使通过光源臂向后传播的光得以恢复，并传递到平衡式光电检测器的另一个输入端[5]。与单检测器相比，平衡式检测具备更高的灵敏度，因为这种检测方式拒绝共模噪声，而且光能利用率更高。因此而产生的干涉信号具有交流耦合的外观。

The swept source emits one wavelength at a time as the filter is tuned through the optical bandwidth of the gain medium. Due to the nature of the various tunable filters, the sweep rate is not necessarily linear in time, and additional steps are required to sample the spectrum *S(k)* at even wavenumber intervals. Some wavelength swept lasers provide a digital pixel clock output synchronized to the filter, for those that do not, a common optoelectronic method to calibrate wavenumber sampling is illustrated in Figure 4. A pixel clock signal which is fed into the waveform digitizer can be generated by using a separate fixed path interferometer, represented by MZI in Figure 3. As the wavelength swept source is tuned through the source spectrum, the fixed interferometer will cross the DC threshold at points evenly spaced in wavenumber. Using this signal as an external pixel clock for the waveform digitizer permits the SS OCT interferogram to be sampled evenly in wavenumber space [6].

通过增益介质的光带宽调谐滤波器时，扫频光源每次发出一个波长。由于不同可调谐滤波器的性质，扫频速率不一定需要线性时间，同时，以均等的光谱间隔进行光谱 *S(k)*采样需要另外的步骤。一些波长扫频激光器提供与滤波器同步的数字像素时钟输出；对于未提供这种像素时钟输出的激光器，采用常见的光电法来标定波数采样，如图 4 所示。使用单独的基准光程干涉仪（如图 3 中的 MZI 所示）可以生成像素时钟信号，该信号馈入数据采集卡。通过光源光谱调谐波长扫频光源时，固定式干涉仪将在均等的波数间隔点跨过直流阈压区。如果将该信号用作数据采集卡的一个外部像素时钟，那么允许以均等的波数间隔对 SS OCT 干涉图进行采样[6]。

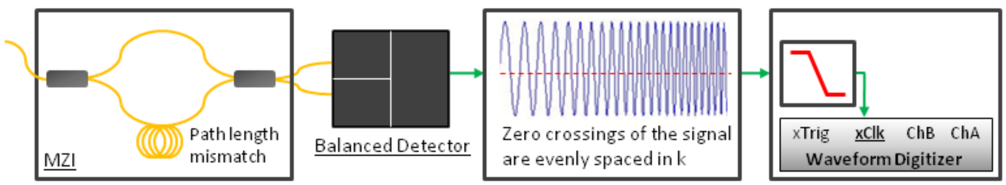


Figure 4: A fixed path Mach Zehnder interferometer (MZI) is used to create a sinusoidal signal whose zero crossing are evenly spaced in wavenumber. This signal can be used as a pixel clock for digitization of the interferometric signal

图 4：使用基准光程马赫曾德尔干涉仪（MZI）创建正弦信号，在波数方面，该信号的零交点间隔都相等。该信号可用作像素时钟，用于干涉信号的数字化。

High-Speed Waveform Digitizer 高速数据采集卡

AlazarTech waveform digitizers enable high-speed acquisition and processing of SS OCT data. The ability of AlazarTech digitizers to guarantee no missed trigger events is crucial particularly in the acquisition of Doppler OCT, which requires calculation of phase difference of adjacent A-scans. High-speed data streaming is achieved through the proprietary Auto Direct Memory Access (AutoDMA) circuitry together with the fully asynchronous driver and dual-DMA engine in AlazarTech digitizers. The combination of these features allows tasks to be performed in parallel fashion. The AutoDMA circuitry uses hardware to re-arm and initiate data transfer which removes software latencies and the dual-port memory acts as a very deep FIFO and dual-DMA engine permitting maximum transfer rates to the PC (limited by the motherboard). The AutoDMA and dual-port memory process is illustrated in Figure 5 and Figure 6, respectively.

AlazarTech 高速数据采集卡实现了 SS OCT 数据的高速采集和处理。AlazarTech 数据采集卡保证不会发生触发事件丢失的情况，特别是在需要计算相邻 A 扫描相位差的多普勒 OCT 采集过程中，这一性能显得至关重要。AlazarTech 数据采集卡专有的自动直接存储器存取（AutoDMA）电路，以及全异步驱动程序和双 DMA 引擎共同实现了高速数据流模式存储。这些特征允许以并行方式执行任务。AutoDMA 电路使用硬件进行重新配置并开始数据传输，该过程消除了软件延时；同时，双端口存储器用作深度 FIFO 与双 DMA 引擎，允许采用传输到计算机的最大传输率（受主板限制）。图 5 和图 6 分别说明了 AutoDMA 和双端口存储器过程。

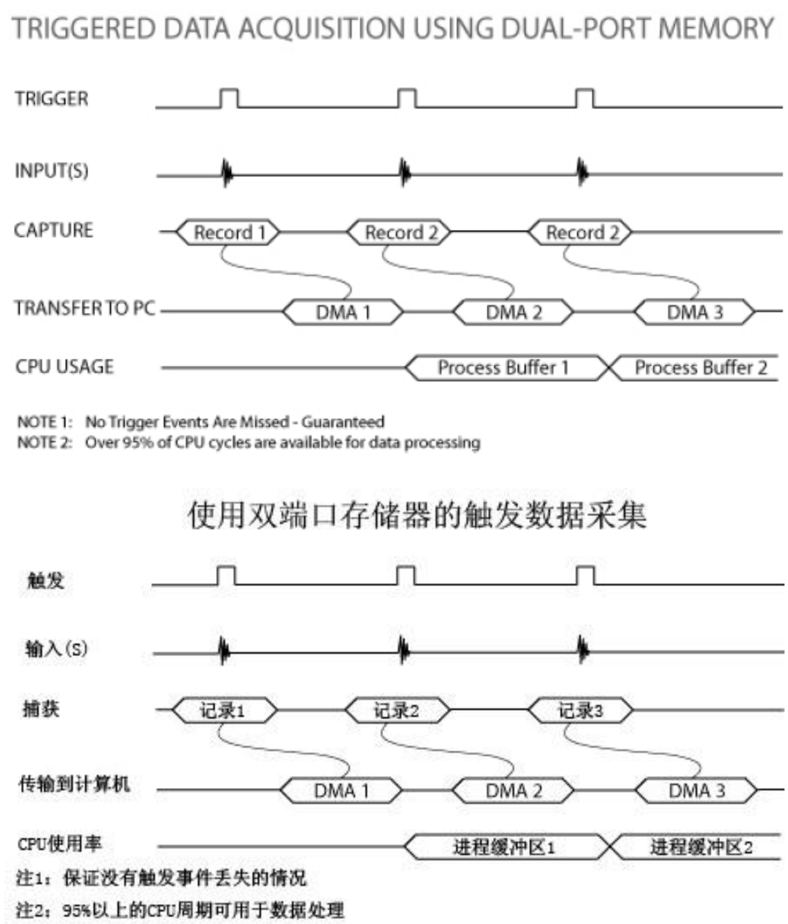


Figure 5: Dual-port memory data acquisition process schematic.

图 5：双端口存储器数据采集过程示意图

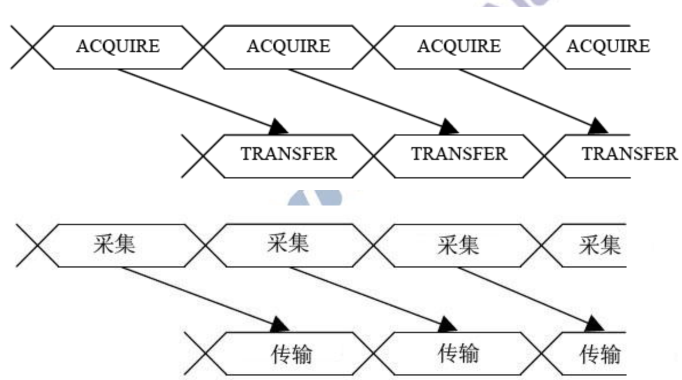


Figure 6: AutoDMA acquire and transfer process.

图 6：AutoDMA 采集和传输过程

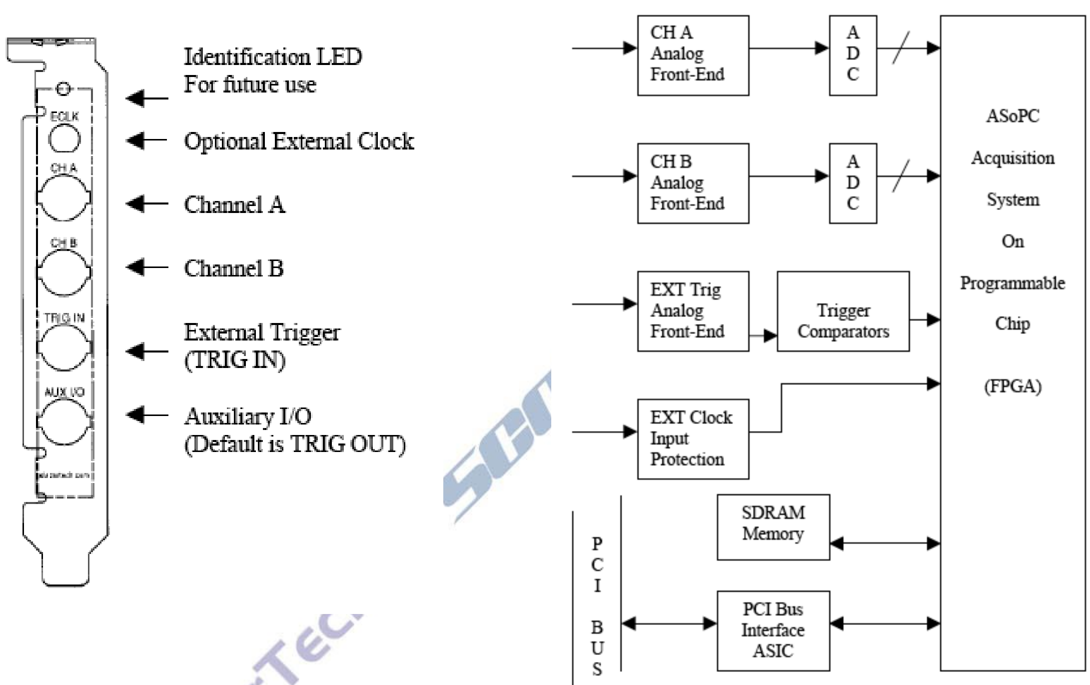
AlazarTech digitizers provide several flavours of AutoDMA—traditional, No Pre-Trigger

(NPT), continuous and triggered streaming. For OCT applications, traditional and NPT are commonly used with the latter being the recommended method. The traditional AutoDMA acquires both pre-trigger and post-trigger data while NPT AutoDMA only captures post-trigger data in each buffer. NPT and traditional AutoDMA can easily acquire and transfer data to the PC at a maximum sustained transfer rate of the motherboard without causing an overflow. One advantage of NPT over traditional AutoDMA is its ability to use the entire on-board memory before an overflow flag is asserted; traditional AutoDMA is only limited to 512 buffers on-board memory if no PC data transfer has been performed.

AlazarTech数据采集卡具有多种AutoDMA模式 – 传统模式、无预触发（NPT）模式、持续和触发流模式存储模式。对于OCT应用，通常使用传统模式和NPT模式，而NPT模式为推荐的首选模式。传统AutoDMA同时采集预触发数据和后触发数据，而NPT AutoDMA只捕获每个缓冲区的后触发数据。NPT和传统AutoDMA可以轻松地采集数据，并以持续的主板最大传输率将数据传输到计算机，该过程不会出现溢出现象。与传统的AutoDMA相比，NPT AutoDMA能够在断定溢出标记之前使用整个板载存储器，这是NPT AutoDMA的一大优势；如果没有执行计算机数据传输，那么传统AutoDMA仅限于512缓冲区的板载存储器。

The ports and architecture schematic of an AlazarTech PCI bus digitizer are shown in Figure 7. Ports consist of an optional external clock input (SMA), two analog input channels (A and B), external trigger analog input and an auxiliary I/O.

AlazarTech PCI 总线数据采集卡的端口和结构示意图（如图 7 所示）。端口包括：一个可选外部时钟输入端（SMA）、两个模拟输入通道（通道 A 和通道 B）、一个外部触发模拟输入端、一个辅助 I/O。



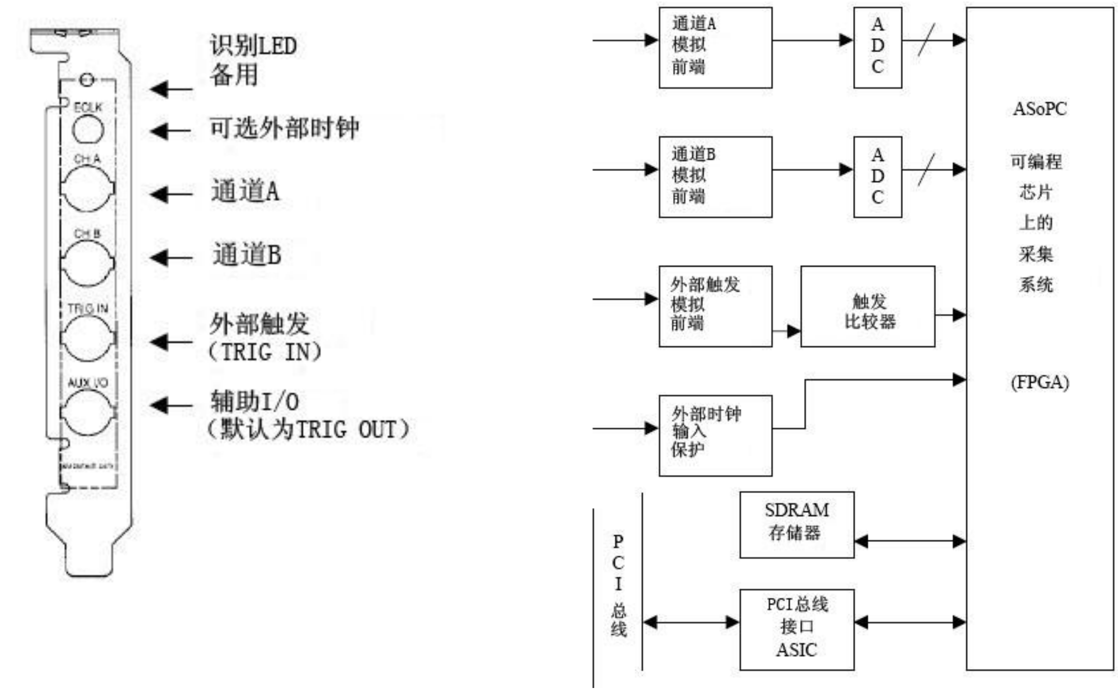


Figure 7: (Left) Digitizer ports. (Right) Basic architecture schematic of a PCI bus digitizer.

图 7：（左）数据采集卡端口；（右）PCI 总线数据采集卡的基本结构示意图

Wavelength swept lasers have several different designs and the output can be a unidirectional sweep or a bidirectional (forward and backward) sweep. Other outputs from a wavelength swept laser are line trigger signals. The line trigger can be generated from an optical reference such as a Fibre Bragg Grating (FBG) or the square waveform triggers can be based on the drive waveform. For swept laser designs with a bidirectional sweep, the user can choose to use the forward sweep, backward sweep or both sweeps by using a combination of the two triggers available. Each AlazarTech board has two trigger engines, wherein channel A or B can be used as an additional trigger source to the existing external trigger. The configurability of the AlazarTech board triggers provides flexibility for working with the different types of wavelength swept lasers.

波长扫频激光器具有多种不同设计，输出可以是单向扫频，也可以是双向（向前、向后）扫频。波长扫频激光器的其它输出为线触发信号。线触发可由光纤布拉格光栅（FBG）等光学基准线生成，或者，方波形触发可以基于驱动波形。对于具备双向扫频设计的扫频激光器，用户可以使用两个可用触发的组合来选择使用向前扫频、向后扫频，或同时向前向后扫频。所有 AlazarTech 数据采集卡产品都具备两个触发引擎，其中，通道 A 或通道 B 可作为现有外部触发的一个额外触发源使用。AlazarTech 数据采集卡触发具有可配置性，这使得 AlazarTech 产品能够灵活地与不同类型的波长扫频激光器共同使用。

The optional External Clock input provides a solution for k-linear SS OCT acquisition. Sampling the OCT signal linearly in k-space using an external pixel clock reduces the overhead of software resampling. The External Clock input on the AlazarTech waveform digitizers can be used with either a digital pixel clock synchronized with the laser sweep (provided by some commercial wavelength swept lasers) or with the analog output from a MZI signal as schematically illustrated in Figure 4. Designed with OCT applications in mind, the AlazarTech series of digitizers are robust to the changing frequencies of the pixel clock signal, and signal dead time in between sweeps.

可选外部时钟输入端为 k 线性 SS OCT 采集提供了一种解决方案。在 k 空间中，使用外部像素时钟对 OCT 信号进行线性采样会减少软件重采样开销。AlazarTech 高速数据采集卡上的外部时钟输入既可以与数字像素时钟一起使用（该像素时钟与某些商用波长扫频激光器提供的激光扫频同步），也可以与 MZI 信号提供的模拟输出一起使用，如图 4 所示。AlazarTech 数据采集卡系列产品在设计时考虑了 OCT 应用，因此对像素时钟信号的变化频率和两次扫频之间的信号死区时间具有较强的适应性。

For the cases were software resampling is preferred, the unused channel can be use to acquire a recalibration signal. The OCT data can then be resampled to be linear in k-space by using any of several algorithms (peak detection, zero crossings, etc.) on the recalibration signal. Both channels on the AlazarTech boards are digitized simultaneously, providing zero-shift between the OCT signal and the recalibration signal. For applications which require more than two inputs, multiple boards can be arranged in a Master/Slave configuration.

在软件重采样为首选方案的情况下，未使用的通道可用于采集重新校准信号。然后，可以使用重新校准信号的任何一种算法（峰值检测、零交点等）对 OCT 数据进行重采样，使其在 k 空间中呈线性。AlazarTech 数据采集卡上的两个通道同时数字化，在 OCT 信号和重新校准信号之间产生零点漂移。对于需要两个以上输入端的应用，可以在主/从配置中布置多个数据采集卡。

AlazarTech has a wide-range of digitizers suitable for OCT applications. They range from 8-16 bit resolution cards with maximum sampling rates of 50MS/s to 1GS/s. For OCT applications, it is recommended to use at least 12-bit resolution digitizer cards. However, with advancement of high-speed SS OCT systems, there is a need for faster PC transfer rates. In this case, an 8-bit card (ATS9870 – 1GS/s, 8-bit) may be more preferred, which has been shown to only reduce the SNR of the OCT signal by ~0.6dB [7]. The wide range of AlazarTech waveform digitizers are complemented by an impressive library of examples and functions with the C/C++ and LabView Software Development Kits (SDK). OCT data acquisition and image processing can be easily integrated into the existing examples in the SDK.

AlazarTech 可提供多种适用于 OCT 应用的数据采集卡。这些产品的分辨率范围从 8 位到 16 位，最大采样率从 50MS/s 到 1GS/s。对于 OCT 应用，建议使用分辨率至少为 12 位的数据采集卡。随着高速 SS OCT 系统的改进，导致需要更快的计算机传输率。在这种情况下，8 位数据采集卡（ATS9870 – 1GS/s，8 位）是更佳的选择；试验表明，该产品的 OCT 信号信噪比只有 ~0.6dB [7]。通过 C/C++和 LabView 软件开发工具包（SDK）的使用，AlazarTech 的多种高速数据采集卡增加了大量示例程序和函数。OCT 数据采集和图片处理可以轻松地应用到 SDK 现有的示例程序中。

References 参考书目

[1] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, and J. G. Fujimoto, "Optical Coherence Tomography," Science **254**, 1178-1181 (1991).

[2] M. Wojtkowski, "High-speed optical coherence tomography: basics and applications High-speed optical coherence tomography: basics and applications," Applied Optics, 49 (16), D30-61, 2010.

[3] J. Fujimoto, W. Drexler, *Optical Coherence Tomography: Technology and Applications.* Springer Berlin Heidelberg, 2008. [E-Book Series] Available: SpringerLink-Book.

[4] B. E. Bouma, and G. J. Tearney, *Handbook of Optical Coherence Tomography.* Dekker, New York, NY, 2001.

[5] A. M. Rollins and J. A. Izatt, "Optimal interferometer designs for optical coherence tomography," Optics Letters. **24**, 1484-1486 (1999).
[6] M. A. Choma, K. Hsu, J. A. Izatt, "Swept source optical coherence tomography using an all-fiber 1300-nm ring laser source," Journal of Biomedical Optics **10**(4), 044009 (2005).
[7] B. D. Goldberg, B. J. Vakoc, W. Oh, M. J. Suter, S. Waxman, M. I. Freilich, B. E. Bouma, and G. J. Tearney, "Performance of reduced bit-depth acquisition for optical frequency domain imaging," Opt. Express **17**, 16957-16968 (2009).

[1] D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, J. G. Fujimoto, "光学相干断层扫描", 科学, 第 254 卷, 1178-1181 (1991).
[2] M. Wojtkowski, "高速光学相干断层扫描：基础和应用", 应用光学, 49 (16), D30-61, 2010.
[3] J. Fujimoto, W. Drexler, 光学相干断层扫描：技术和应用. 海德堡柏林: 施普林格出版社, 2008. [电子图书系列]可提供：SpringerLink 电子丛书.
[4] B. E. Bouma, G. J. Tearney, 高速光学相干断层扫描手册. 纽约州纽约市: 德克尔出版社, 2001.
[5] A. M. Rollins, J. A. Izatt, "光学相干断层扫描的最佳干涉仪设计", 光学快报, 第 24 卷, 1484-1486 (1999).
[6] M. A. Choma, K. Hsu, J. A. Izatt, "使用全光纤 1300-nm 环形激光源的扫频光源光学相干断层扫描", 生物医学光学杂志, 第 10(4)期, 044009 (2005).
[7] B. D. Goldberg, B. J. Vakoc, W. Oh, M. J. Suter, S. Waxman, M. I. Freilich, B. E. Bouma, G. J. Tearney, "用于光频域成像的降低位深度采集的性能", 光学快讯, 第 17 卷, 16957-16968 (2009).