References

<table>
<thead>
<tr>
<th>Title</th>
<th>Author(s)</th>
<th>Journal</th>
<th>Institute</th>
</tr>
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<tbody>
<tr>
<td>High speed wavelength-swept laser source with High Locality Sweep for optical coherence tomography</td>
<td>Changho Chong, Atsushi Morosawa, Toru Sakai, Masahide Itoh and Toyohiko Yatagai</td>
<td>IEEJ 2007</td>
<td>Santec Corporation</td>
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<tr>
<td>Spectral Norman Effect by Quasi-Phase Continuous Tuning of High Wavelength-Swept Light Source</td>
<td>Changho Chong, Takuya, Satoki, Atsukeshi Morosawa, Toru Sakai, Masahiko Nakahara</td>
<td>Optical Express Vol. 6, No. 25, 21022-21028, December 20, 2008</td>
<td>Santec Corporation</td>
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<tr>
<td>Large Core Diamter Length Sweep Source for Axial Length Measurement of Eye</td>
<td>Changho Chong, Satoki, Koichi Tokuda, Atsukeshi Morosawa, Toru Sakai</td>
<td>Optics Express Vol. 4, No. 10</td>
<td>Santec Corporation</td>
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<tr>
<td>In vivo three-dimensional microelectromechanical endoscopic swept source optical coherence tomography</td>
<td>Jun Zhang, Jing Su, Jun Zhang, 2 Lefou L., 2 Hongjing Chen</td>
<td>8 August 2007 / Vol. 15, No. 16 / OPTICS EXPRESS 15930</td>
<td>Univ. of California, Irvine</td>
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<tr>
<td>Three-dimensional and high-speed immersion optical coherence tomography for in vivo investigation of human anterior eye segments</td>
<td>Shoude Chang, Biomedical Imaging: From Nano</td>
<td>Santec Corporation</td>
<td></td>
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<td>Multifaceted Fourier domain-OCT system with superior signal resolution for biological applications</td>
<td>Jun Holmes, Simon Hattington, Nick Stone, Graham Basant-Wright, and Hugh Ben</td>
<td>Proc. SPIE Vol. 6847, 68470J (Feb. 16, 2008)</td>
<td>McMaster University, Canada</td>
</tr>
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<td>Multifocal swept source optical coherence tomography imaging of the human arteries using a microelectromechanical endoscope and digital signal processor</td>
<td>Jing Su, Xian Zhang, and Lianzheng Li</td>
<td>Journal of Biomedical Optics 2008, 13, 3:035001-1-3</td>
<td>Univ. of California, Irvine</td>
</tr>
<tr>
<td>Three-dimensional swept source optical coherence tomography using silicon MEMS Scanner for high speed swept-source OCT</td>
<td>Kunan K.; Condit, J.C.; McEnery, A.; McShane, K., Miller, T.; Arey, Jing Peng;</td>
<td>Proc. SPIE Vol. 6711, 67110C (November 2007)</td>
<td>UTexas</td>
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<td>Effective indicators for diagnosis of oral cancer using optical coherence tomography</td>
<td>Jianping Su, Jun Zhang, Jianping Su, Kenneth chang, and Hongjing Chen</td>
<td>Proc. SPIE Vol. 6847, 68473Y (Feb. 18, 2008)</td>
<td>University of Houston, USA</td>
</tr>
<tr>
<td>Functional optical sweep-coherent optical coherence tomography for imaging and quantifying of microbubles in a带动bloodstream</td>
<td>Han-Kim Kang, T. G. Comer, R. J. Voy, and K. L. Syn</td>
<td>J. Appl. Phys. / Volume 105 / Issue 10 / SPECIAL TOPIC: APPLIED BIOPHYSICS</td>
<td>University of Houston, USA</td>
</tr>
</tbody>
</table>
OCT Image Gallery

Medical Diagnostics

Developmental Biology

Industrial Inspection

Our Products

Systems

Hi-Performance *IVS-2000 Series*

Portable *IVS-300 Series*

Lasers

Components

MEMS structure

IC package

Liquid Crystal Display

Coating on the drug

Paint

Molded plastic

Probe

Balanced Photo detector

DAQ board

Interferometer

Analysis Software
The Santec swept source OCT system, IVS-1000/2000 is designed for research, feasibility studies and product development. Utilizing the best selling Santec HSL series lasers, the system can be configured to address a wide range of applications. With an extensive choice of lasers, interferometers, probes and software, the IVS-1000/2000 is our most flexible platform for SS-OCT. Santec also supports user development by disclosing the OCT software.

Non-destructive testing is one of the key functions in product quality control. In-line inspection to detect voids, cracks, delamination and defects can be realized by using OCT. The operation wavelength 1.7 μm system newly added to the lineup has small scattering, so the imaging depth improves and high-speed and accurate measurement is possible (IVS-4000).

**Wavelength range**

The choice of wavelength range in OCT is dependent on the water absorption and scattering properties of the sample or tissue of interest. In general, 800nm range is used for retinal imaging because of low absorption in vitreous humor, and recently 1060nm range gains attentions because of large penetration in retinal tissue as well as low dispersion property in tissues. In endoscopic applications, the 1310nm range or a longer range is commonly used because of low scattering, resulting in large depth penetration. OCT in the 1310nm range has another benefit: abundant available optical components in this range that were developed for optical fiber telecommunication applications. The spectral width of the OCT signal, i.e., axial resolution, is inversely related to the envelope of temporal power profile via Fourier transforms, and which is given by the equation on the previous page. For example, using this equation: 10μm resolution can be achieved by: 30nm at 820nm or 75nm at 1310nm.

**Instantaneous linewidth / Coherence length**

Instantaneous linewidth is a terminology very specific to the high-speed swept-source. Sometimes it is called, dynamic linewidth. It doesn’t mean the linewidth of a single longitudinal mode as usually referred to in laser oscillation definitions. Most of the swept sources for SS-OCT are partially coherent light sources, and therefore spectral width is the width of the envelope that contains the group of cavity modes. Since instantaneous linewidth is finite and the OCT signal is a convolution of its spectrum and interferogram, its fringe visibility drops for the higher frequency components, i.e., at deeper range. Coherence length is defined as the optical round trip delay or twice of the depth range where fringe visibility drops half or the Fourier-transformed OCT signal drops 6dB compared to the signal power at zero delay.

**Relative Intensity Noise**

Intensity noise of the source at the signal detection band directly impacts on the SNR of the OCT system. Source of the noise attributes to the injection current from the driver circuitry and the cavity mode beating and its harmonics at the frequency equal to the reciprocal of cavity life time. Ripple on the spectral profile of the sweep also influences on the OCT signal as an alias noise. In the OCT system, the source RIN can be reduced if balanced detection is used for common mode noise reduction. RIN can be measured with a photodiode and an electrical spectrum analyzer.

**Polarization**

Single polarization output or output with high degree of polarization (DOP) is desired to suppress the effect of PMD in the interferometry system. Single polarization output may be useful when polarization sensitive OCT can be realized by adapting the Mueller matrix method.

**Reliability**

Long term reliability and durability of the source is desired for harsh environmental conditions in clinical use. Meeting EMC/EMI standards is also important so that the instrument doesn’t interfere with the other surrounding equipments. In most cases, 5 years product life should apply, corresponding to over average 40,000hrs of continuous usage.

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**Typical specifications**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swept source</td>
<td>HSL series</td>
<td></td>
</tr>
<tr>
<td>Interferometer</td>
<td>Mach-Zehnder type</td>
<td>Other custom available</td>
</tr>
<tr>
<td>Probe</td>
<td>Microscope/Handheld type</td>
<td>2D, 3D</td>
</tr>
<tr>
<td>DAQ board</td>
<td>Special FPGA type</td>
<td>Real time displaying up to 25-30ps</td>
</tr>
<tr>
<td>PC</td>
<td>Quad-core 2.4GHz clock</td>
<td>Windows 7</td>
</tr>
<tr>
<td>Software</td>
<td>OCT software</td>
<td>LabVIEW10.1 required VI file can be disclosed by option</td>
</tr>
<tr>
<td>Option</td>
<td>Foot switch</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Microscope Stand</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High Repeatability (~0.1μm)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>measurement System</td>
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**Wavelength range**

<table>
<thead>
<tr>
<th>Model No.</th>
<th>Center Wavelength</th>
<th>Features</th>
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</thead>
<tbody>
<tr>
<td>IVS-4000-STR</td>
<td>1700nm</td>
<td>MEMS Type 90kHz A-line</td>
</tr>
<tr>
<td>IVS-2000-HS</td>
<td>1310nm</td>
<td>MEMS Type High Speed 100kHz A-line</td>
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<tr>
<td>IVS-2000-LC</td>
<td>1310nm</td>
<td>MEMS Type Long Coherence Length, 50kHz A-line</td>
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<tr>
<td>IVS-2000-ST</td>
<td>1310nm</td>
<td>Polygon scanner Type General and In-line Inspection</td>
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<tr>
<td>IVS-2000-HR</td>
<td>1310nm</td>
<td>Polygon scanner Type High Resolution</td>
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<tr>
<td>IVS-1000-VCSEL</td>
<td>1060nm</td>
<td>Tunable VCSEL Type</td>
</tr>
</tbody>
</table>
Santec introduces the latest generation of SS-OCT console, the IVS-300. The IVS-300 combines highly integrated all-in-one design with intuitive ease-of-use to deliver advanced imaging capabilities straight out of the box. With cutting edge features, functions and benefits the IVS-300 empowers clinicians and researchers to effectively image and measure a range of parameters with the high sensitivity associated with the swept source OCT technique. OCT is proving itself an exceptional tool for below the surface imaging for a range of applications in medical, dental, material processing and research fields. The IVS-300 system's control software and ergonomic hardware design delivers this highly sophisticated imaging technology at an entry level price.

**Parameter Specification**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swept source</td>
<td>HSL series</td>
<td></td>
</tr>
<tr>
<td>Probe</td>
<td>Long neck type, Grip type</td>
<td>Built in Mach-Zehnder interferometer</td>
</tr>
<tr>
<td>DAQ board</td>
<td>Special FPGA type 100MHz, 12bit</td>
<td>Real time displaying up to 25-30fps</td>
</tr>
<tr>
<td>PC</td>
<td>Quad-core 2.4GHz clock</td>
<td>Windows 7</td>
</tr>
<tr>
<td>Software</td>
<td>OCT software, Viewer software</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>CP-OCT available, CP = Cross Polarization</td>
<td></td>
</tr>
</tbody>
</table>

**Importance Parameters in SS-OCT**

**Swept range ⇒ Axial resolution**

\[ \delta z = \frac{2 \ln 2}{\pi} \frac{\lambda_0^2}{\lambda} \frac{\text{Swept range}}{\text{Wavelength}} \]

**Coherence length ⇒ Depth range**

\[ cL = \Delta L \times 2 = 2 \ln 2 \frac{\lambda_0^2}{\lambda} \frac{\text{Swept range}}{\text{Linewidth}} \]

**Swept rate ⇒ Imaging speed**

\[ f_r = \frac{f_{\text{swept}}}{NA} \text{ A-lines/frame} \]

**Output power**
The higher the output power on the sample, the higher the SNR improves in principle. However, maximum permissible exposure on the human tissue is regulated by ANSI (American National Standards Institute) standard. An average power of 0.7mW in the 800nm wavelength range, and about 1mW in the 1060nm wavelength range, at the probe arm, are the maximum allowable exposures for ophthalmic applications. Other tissues can be exposed to >10mW average power in endoscopic applications. At even longer wavelengths, such as 1300nm, higher powers can be used, as the maximum power becomes less critical in terms of ionization of tissue by high power exposure.

**Sweep linearity**
The OCT signal is processed by time-sampling the backscattered light as the swept source sweeps the wavelength followed by Fourier transform (FFT). Ideally, the sweep should be linear in k space (k=2π/λ). But actual sweep curves of most of the proposed swept sources are non-linear in time, because of the intrinsic tuning mechanism. For example, the use of Galvano mirror or fiber Fabry-Perot filter imposes sinusoidal sweep due to its driving characteristics. If simply applying FFT on the time-sampled interferogram when this non-linearity is present, the resolution of the signal is blurred and the signal power also decays. So, in general, most SS-OCT systems implement either nonlinear sampling with the use of an optical clock having another set of interferometer and detector, or the post processing approach; the so called “wavelength rescaling process”.

**Swept rate (scanning speed)**

Wavelength swept rate, or scanning speed of the swept source is directly reflected on the imaging speed like the readout speed or refresh rate of the CCD in SD-OCT. Swept rate corresponds to A-line rate in OCT. Increasing A-line rate makes it possible to accommodate more A-lines per frame or increase the frame rate. In practical applications, the ability to produce video rate images is of critical importance. This not only removes imaging artifacts that are created by undesired movement, but also enables a large area/volume measurement without compromising resolution, in a short amount of time. Depending on the applications, swept rate of 10 kHz to 100 kHz range are required.
Feature of IVS software

- Proprietary rescaling algorithm integrated FPGA DAQ board
- Real time imaging up to 30fps
- 1D, 2D, 3D imaging mode
- Storage mode for time elapsed measurement
- Scan angle setting arbitrary angle scan
- OCT graph capture, Raw data import/export
- Custom settings Viewing area (IVS-2000)
- Thickness, distance analysis software for industrial application available (IVS-2000)
- LabVIEW Sub-Vi files, source codes are available as option
- Free 3D viewer attached

Background of Swept Source-OCT

OCT is a non-invasive imaging technique that was originally introduced in the early 1990’s. Diagnosis systems based on this technique are now widely practiced in ophthalmologic applications.

Compared to conventional medical imaging technologies such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), X-Ray Computerized Tomography (CT) and Ultrasonography, OCT provides a safe, high resolution solution at a cost point that will enable widespread use in hospitals and clinics. Most of these OCT systems used Time-Domain optical interferometry in which the optical path length difference between the reference mirror and the sample in the Michelson or Mach-Zehnder interferometer is modulated in time. Time-Domain or TD-OCT had opened up the potential of optical biopsy but there are performance limitations for further extension of the applications. First, imaging speed is relatively slow because of mechanical delay modulation. Second, even when higher frequency scanning is possible, detection sensitivity drops because of detection bandwidth in return. Fourier-Domain OCT is a break-through technology which enables high sensitivity and high speed imaging at the same time. FD-OCT relies on analyzing the individual frequency components of backscattered light from the sample or tissue. There are two methods within FD-OCT. One is Spectral-Domain OCT (SD-OCT) which uses a low coherence light source and a spectrometer, where frequency components are spatially analyzed on the CCD array. The fast readout speed of CCD provides high imaging speed, and high signal-to-noise ratio (SNR) gives 20-30dB advantage over conventional TD-OCT. However, there are also disadvantages. Images get blurred and degraded when the sample arm motion washes out interference fringes on the CCD during the pixel integration time. Furthermore, unavailability of an InGaAs CCD with higher pixel resolution also limits the application of FD-OCT for in-vivo endoscopic applications. The other approach is Swept-Source OCT which uses a continuous and repetitively tunable (or “swept”) light source where frequency components are analyzed in time with a single photodetector. Each wavelength scan generates depth information; lateral scanning of the laser beam then enables a cross section image to be constructed. This technique has a theoretical sensitivity benefit equal to that of SD-OCT, while overcoming the disadvantages of SD-OCT such as fringe washout, and allowing the use of longer wavelengths, over 1 μm to 1.5 μm range, for endoscopy.

Santec introduced a variety of swept sources that realize high speed, high resolution OCT imaging with extremely high reliability.

SS-OCT principle

Each scan of wavelengths produces an interference pattern signal by the reflections at different depths. Depth dependent reflection profiles are calculated by Fourier transform of the interferogram. Repeating this A-scan at different locations produces a two dimensional cross section.
SANTEC CORPORATION

Handheld probes and small endoscopic probes are available as custom options for SS-OCT systems and OEM solutions.

Handheld probes

Handheld probes with a fixing aperture attachment provide 2D and 3D imaging capability which is ideal for oral/dental application as well as for the diagnostics of skin. A Microscope type is also available with integrated CCD camera for target area searching.

Lateral resolution and Confocal parameter (Depth of Focus (DOF))

NA (numerical aperture) or focal length, f of an objective lens and beam diameter, D inside the probe determines the spot size (w0), or the lateral resolution and depth of focus (DOF). Graph shows typical relation of these two parameters. If targeting depth range is shallow, DOF can be compromised over small lateral resolution, or vice versa.

TUTORIAL

Typical variations

<table>
<thead>
<tr>
<th>d (µm)</th>
<th>DOF (mm)</th>
</tr>
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<tbody>
<tr>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>35</td>
<td>3.3</td>
</tr>
<tr>
<td>45</td>
<td>7.7</td>
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</table>

Lateral resolution

Low NA

High NA

Confocal parameter

NA

$d = \frac{4f}{NA}$

$DOF = \frac{2\pi f}{\lambda}$

Support

- Technology support for feasibility study in medical, industrial applications
- OEM manufacturing
- Technology transfer

Santec is a global photonics engineering company and a leading manufacturer of Tunable Lasers, Optical Test and Measurement Products, and Advanced Optical Components. Santec is a dynamic venture spirited company established in 1979, celebrating more than 38 years in optical innovations. Santec introduced the world’s first tunable laser based on external cavity structure and semiconductor laser in 1986. Santec’s advanced tunable laser, the HSL-2000, was developed specifically for OCT applications utilizing patented innovative design and expertise on tunable lasers accumulated over the past 25 years. Featuring high power, wide tuning, fast scan rates and more, the HSL-2000 offers a high specification laser to achieve high resolution 3-D imaging and high resolution real time 2-D imaging. Santec also offers balanced detectors, imaging probes, and a complete OCT system, IVS-2000, which utilizes the HSL-2000.

Santec’s advanced tunable laser, the HSL-2000, was developed specifically for OCT applications utilizing patented innovative design and expertise on tunable lasers accumulated over the past 25 years. Featuring high power, wide tuning, fast scan rates and more, the HSL-2000 offers a high specification laser to achieve high resolution 3-D imaging and high resolution real time 2-D imaging. Santec also offers balanced detectors, imaging probes, and a complete OCT system, IVS-2000, which utilizes the HSL-2000.
Features of Swept Sources

MEMS based HSL (HSL-20, -40)
HSL-20, -40 is an integrated MEMS based swept source that outperforms other lasers in speed, coherence length and scan range. Santec’s proprietary design realizes the fastest swept rates up to 100kHz while maintaining stable operation. The source is equipped with k-trigger and start-trigger for system synchronization.

HSL-20-100
HSL-20-100 has a high speed scanning speed at 1.31μm wavelength range. It’s a suitable laser for high speed imaging application such as cardio vascular imaging.

100kHz @ 1.31μm

HSL-40
Non-destructive testing is one of the key function in product quality control. In-line inspection to detect Void, Crack, Delamination and Defects can be realized by using OCT. HSL-40 delivers fast and accurate measurements with enhanced imaging depth thanks to low scatter at its operating wavelength, 1.7μm.

90kHz @ 1.7μm

BPD-200, -200-HS
BPD-200 is a balanced photo detector that outputs the difference of two detector signals. This can be used for reduction of common mode noise due to the laser power fluctuation. In heterodyne detection as in most of OCT applications, balance detection yields 3dB sensitivity advantage when detecting the signal inverted in phase in between two input signals. Furthermore, special design significantly reduced the problem of the undesired image artifact which was a major problem in the other balanced detectors. BPD-200 is the best detector ever made specifically for SS-OCT applications.

Features
- Wide dynamic range (DC to 80MHz), (DC to 200MHz)
- High reliability and high gain, high linearity
- Flat balanced level
- Specially designed for artifact-reduction

Applications
- Swept Source - OCT
- Heterodyne measurement
- OFDR (Optical Frequency Domain Reflectometry)

IFM-200
IFM-200 is an OEM module of a Mach-Zehnder type interferometer. A wide range of configurations can be realized based upon customer requirements including PS-OCT with added features such as targeting diode laser, and optical delay line. Thirty years of optical integration and packaging experience is applied to maintain high quality and high reliability as well as optimizing cost. Custom configuration including other interferometer types (ex. Michelson, Fizeau type) can be designed for OEM solutions.

Features
- Custom configuration (Michelson, Mach-Zehnder, Fizeau, etc)
- Optical delay line, variable attenuator, polarization controller optional integration
- PMF type also available

Output Power (mW)
Trigger Voltage (V)
Wavelength (nm)
Time (μs)

S/N: 14035002 Optical Characteristics @100kHz

Guillermo J. Tearney, et al.
J. of Biomedical Optics
Mar 2006 Vol 11 No.2

Guillermo J. Tearney, et al.
J. of Biomedical Optics
Mar 2006 Vol 11 No.2

Yan Li , Joseph Jing , Emon Heidari , Jiang Zhu , Yueqiao Qu & Zhongping Chen,
“Intravascular Optical Coherence Tomography for Characterization of Atherosclerosis with a 1.7 Micron Swept-Source Laser”
nature.com Scientific Reports 7, Article number: 14525(2017)
OEM solutions

HSL-20, -40
HSL-20, -40 offer a small footprint ideal for system integration, with cutting edge optical performance. Available in the 1.3 and 1.7 micron wavelength ranges, the HSL feature fast scanning and long coherence and deliver the best imaging performance. Already in volume production and with capacity to grow, Santec is your ideal OEM partner.

Features
- High scanning speed
- Small foot print

Applications
- OEM source for OCT systems
- OEM source for sensing systems

HSL-200
HSL-200 is based on our market leading polygon scanning laser. Our most diverse laser in terms of specifications available, the HSL-200 can be used in a wide range of configurations to optimize image quality. With over 50,000hrs of use in the field these lasers have proven reliability. Maintaining the same high performance of bench-top laser, the size is miniaturized with an external power supply and supports RS-232C communication for control and monitoring. Specifications (ex. Scan rate, scan range, coherence length, output power, etc) can be customized to fit to OEM solutions.

Features
- High linearity and repeatability
- Compact design

Applications
- OEM source for OCT systems
- OEM source for in-line inspection systems

Tunable VCSEL (HSL-1)
The HSL-1 is based on advanced electrically pumped VCSEL (Vertical Cavity Surface Emitting Laser) technology. An attractive laser for SS-OCT applications the HSL-1 takes advantage of a number of features intrinsic to VCSELs to deliver best-in-class performance, including long coherence length, variable scan speed and low signal noise.

HSL-1
The HSL-1 has been designed with system integration in mind, a compact, efficient package the laser is also robust, reliable and suitable for mass production.

Ultra Long Coherence Length

Polygon scanner based HSL (HSL-2100)
Santec’s polygon scanner based HSL is a bestselling product for SS-OCT. This laser has been successfully integrated in a range of FDA approved medical OCT systems. The HSL-2100 lasers feature high scan linearity with high repeatability, meaning users can build OCT without need for k-clock sampling, significantly reducing the complexity of the OCT system as a whole. Realizing a simple SS-OCT configuration while minimizing cost.

HSL-2100WR
HSL-2100WR guarantees 170nm, the widest swept range for ultra-high resolution OCT imaging. Theoretical axial resolution of about 5 microns is possible with the maximum swept rate of 20kHz. It’s a suitable performance for skin and cancer imaging.

Wide scanning

Power [dBm]

Wavelength [nm]
### Specifications of Swept source

#### MEMS based HSL

- **HSL-2100, -200**
  - **Standard**
    - Center Wavelength: 1315-1340 nm
    - Scan Range: ≥110 mm
    - Output Power: ≥20 mW
    - Scan Rate: 20 kHz
    - Coherence length: ≥5 mm
    - Duty Cycle: ≥65%
    - Trigger: -
    - Output Optical Fiber: SMF
    - Operation Environment
      - Temperature: 15-35°C
      - Humidity: <80%, no condensation
    - Electric Power: -
    - Power Consumption: VA
    - Size (W x D x H): 343 x 376 x 153 mm
    - Weight: 10 kg
  - **Wide Range**
    - Center Wavelength: 1290-1320 nm
    - Scan Range: ≥170 mm
    - Output Power: ≥20 mW
    - Scan Rate: 20 kHz
    - Coherence length: ≥6 mm
    - Duty Cycle: ≥60%
    - Trigger: -
    - Output Optical Fiber: SMF
    - Operation Environment
      - Temperature: 15-35°C
      - Humidity: <80%, no condensation
    - Electric Power: -
    - Power Consumption: VA
    - Size (W x D x H): 343 x 376 x 153 mm
    - Weight: 10 kg
  - **Long Coherence**
    - Center Wavelength: 1300-1330 nm
    - Scan Range: ≥35 mm
    - Output Power: ≥9 mW
    - Scan Rate: 9 kHz
    - Coherence length: ≥9 mm
    - Duty Cycle: ≥65%
    - Trigger: -
    - Output Optical Fiber: FC connector APC polish
    - Operation Environment
      - Temperature: 15-35°C
      - Humidity: <80%, no condensation
    - Electric Power: -
    - Power Consumption: VA
    - Size (W x D x H): 200 x 300 x 95 mm
    - Weight: 6 kg

#### Tunable VCSEL

- **HSL-20, -40**
  - Center Wavelength: 1315-1340 nm
  - Scan Range: ≥100 mm
  - Output Power: ≥40 mW
  - Scan Rate: 50 kHz
  - Coherence length: ≥20 mm
  - Duty Cycle: ≥45%
  - Trigger: Integrated Start Trigger and k-Trigger
  - Output Optical Fiber: SMF
  - Operation Environment
    - Temperature: 15-35°C
    - Humidity: <80%, no condensation
  - Electric Power: -
  - Power Consumption: VA
  - Size (W x D x H): 134 x 194 x 54 mm
  - Weight: 2 kg

#### Polygon scanner based HSL

- **HSL-2100, -200**
  - Center Wavelength: 1315-1340 nm
  - Scan Range: ≥110 mm
  - Output Power: ≥20 mW
  - Scan Rate: 20 kHz
  - Coherence length: ≥5 mm
  - Duty Cycle: ≥65%
  - Trigger: -
  - Output Optical Fiber: SMF
  - Operation Environment
    - Temperature: 15-35°C
    - Humidity: <80%, no condensation
  - Electric Power: -
  - Power Consumption: VA
  - Size (W x D x H): 343 x 376 x 153 mm
  - Weight: 10 kg

#### HSL-1

- Center Wavelength: 1290-1320 nm
- Scan Range: ≥170 mm
- Output Power: ≥20 mW
- Scan Rate: 20 kHz
- Coherence length: ≥6 mm
- Duty Cycle: ≥60%
- Trigger: -
- Output Optical Fiber: FC connector APC polish
- Operation Environment
  - Temperature: 15-35°C
  - Humidity: <80%, no condensation
- Electric Power: -
- Power Consumption: VA
- Size (W x D x H): 200 x 300 x 95 mm
- Weight: 6 kg

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*1: -10dB bandwidth
*2: Round trip path length @-6dB signal drop. Ex) 10mm coherence length = 5mm depth @-6dB down signal drop in OCT image