CESARE SVELTO

Biography of Prof. Svelto

Cesare Svelto (S'94–M'97) was born in Bari, Italy, in 1968. He received the M.S. degree in Electronics Engineering (*cum laude*) from University of Pavia, Pavia, Italy, and the Ph.D. degree in Electronics and Communication Engineering from Politecnico di Milano, Milan, Italy, in 1993 and 1997, respectively.

In 1996, he joined the Electronic and Information Science Department, Politecnico di Milano, as an Assistant Professor of electronic measurements, where from 2002 to 2006 he was an Associate Professor of electronic measurements. Since 2006, he has been a Full Professor of electronic measurements.

In Politecnico di Milano and, Prof. Svelto has been teaching in different academic courses of Engineering: Electronic Measurements, Fundamentals of Measurements, Statistics and Measurements, Data Acquisition Systems, Optical Measurements, Circuit and Electronic Measurements. A number of about 5000 university students followed his courses in more than 20 years of didactical activity.

Prof. Svelto is the author of more than 250 papers published in international journals or international conference proceedings. His main research activities are in the fields of optical frequency standards, phase noise measurements and frequency stabilization of laser and electronic oscillators, biomedical measurements, fluidodynamical velocimetry, and electrooptical instrumentation and measurements.

Dr. Svelto is a member of the IEEE Instrumentation and Measurements Society and of the Italian Association "Group of Electrical and Electronic Measurements (GMEE)". In 1997, he was awarded the Philip Morris Prize for his Ph.D. thesis on the absolute frequency stabilization of solid-state lasers.

Overview of Prof. Svelto's Research Activities

Optoelectronic Measurements and Frequency Metrology

1. Measurements in Wavelength Division Multiplexing (WDM) optical communications systems

WDM optical communication systems are very important broadband communication systems. In this context, a coherent optical communication system with four-channel transmission capacity of 622 Mbit/s × 4 ≈ 2.5 Gbit/s was developed and characterized at CSELT laboratories in Turin. On this system different optical and electronic measurements of the laser spectra as the local oscillator were performed, to overcome crosstalk between adjacent channels, and those relating to the error rate (*Bit-Error-Rate*) of the transmission. In the course of experimental work, an *original method of measurement for* angular alignment between the direction of polarization of linearly polarized laser beam and the axes of birefringence of polarization maintaining fiber has been also developed. The novel multichannel system and the new measurement methodology are currently being used in CSELT laboratories.

2. Characterization of innovative laser oscillators for high-resolution measurements and for the realization of frequency references

Solid state lasers pumped by semiconductor diodes, constitute an important class of optical frequency oscillators for their high spectral purity that makes them interesting measurement systems and optical references, in those applications where the natural characteristics of high consistency are essential. In this context, innovative laser sources such as Nd:YAG, Er-Yb:glass, Tm:YAG or Tm-Ho:YAG, and Tm-Ho:KYF have been developed and characterized. In particular, different single-frequency lasers were developed based on neodymium (λ = 1.06 μm), thulium (λ = 2.02 μm), and thuliumholmium (λ = 2.097 μm) in YAG crystal matrix. These sources are of interest in basic optical metrology, to connect different frequency references from the infrared to the visible region.

In the context of research funded by ASI and by MURST, a portable system consisting of an Nd:YAG laser duplicated and stabilized in frequency at 532 nm, was developed in collaboration with IMGC and recommended as a reference at international level. The intercomparison of results from standards developed in Germany, France, and Italy confirmed that the portable system achieved performance at world level class. This has been achieved due to an improvement of optical and electronic parts of the portable system which were verified with an accurate characterization of the components with refined measures of frequency stability. Measures of frequency separation between different iodine hyperfine lines have provided accurate results as the best global measures confirming the high system performance achieved.

Optical sources at 2.1 μm sources Tm:YAG laser, or Tm-Ho:YAG, portable compact, and possibly stabilized compared to absolute references, make up one side of the original development frequency reference chain extension from visible to infrared and the other as a goal of its own to make the reference oscillator tunable, compact and low power consumption for a meteorological measuring system (Lidar-Doppler) from satellite to Earth. The performance of this system, in terms of frequency stability and accuracy, have turned several research programs currently at NASA and ESA. In this area, research programs for the connection of 150 THz frequency (2 μm) to ~500 THz (532 nm) and for the realization of a continuous wave oscillator with very dense and high frequency stability at 2.1 μm, suitable for measuring atmospheric LIDAR-Doppler by satellite are being developed at the Department of electronics and information. Special attention was paid to Er-Yb laser: glass where Prof. Svelto has found interesting applications in optical communications frequency references to 1.5 μm (continuous oscillator), and in optical communications (pulsed oscillator). Also in this case the realization of such innovative sources with high spectral purity could offer superior results to those traditionally obtained with external cavity diode lasers. In this area, (*i*) a new compact laser (*microchip*) with high efficiency and spectral purity; (*ii*) a laser that operates for the first time in harmonic *mode-locking* scheme which provides pulses of duration between 4 ps and 30ps, with a repetition frequency of 2.5 GHz suitable for soliton waveguides; (*iii*) a laser up and running in continuous duty with spectral wavelength tunable over a wide range (from 1571 nm to 1528 nm), were developed and characterized. For the optimization of these optical frequency oscillators, special attention was paid to the measurements of the different parameters in the spectral domain and/or in the time domain. In this field, Prof. Svelto has dealt with a variety of optical and optoelectronic measurements such as power measurements of amplitude noise, measurements of Gaussian laser beams profile and beam divergence, wavelength tunability and measurements of frequency stability using spectral analysis and sampling variances which are specific to time and frequency characterizations. The interesting aspect in characterizing these laser oscillators was the development or deeper understanding of electronic measurement techniques for the detection of significant parameters of the optical signal under measurement.

3. Noise measurements of frequency and amplitude in particular applied to the solid state laser sources

Noise measurements on stable oscillators require analytical methods to ensure a remarkable accuracy. In particular, the analysis of the properties of optical oscillators with high consistency requires refined techniques for opto-electronic measurements the signal power resulting from the laser source. Solid state lasers pumped by semiconductor diodes, due to their inherent spectral purity, lend themselves perfectly to an active stabilization of the oscillation frequency. These sources of stabilized frequency are useful for optical metrology applications with high resolution spectroscopic measurements such as WDM optical communications and optoelectronics sensors, and LIDAR measurement systems. In particular, Prof. Svelto stabilized and developed the following sources: (*i*) A single-frequency Nd:YAG laser with high spectral purity ($\Delta\nu_0$<20 kHz for ν_0≅282 THz) and high optical power output (P~0.8 W), and other actively frequency stabilized commercial sources of NPRO type. (*ii*) Different laser sources that are erbium-ytterbium stabilized compared to *bulk*-type molecular transitions of acetylene (C_2H_2) in ~1.5 μm with *fringe-side locking* or Pound-Drever or free running methods. Depending on the experiment, line widths and relative long-term frequency instability, measured on the signals between two stabilized lasers were 10^{-8} and 10^{-11} (50 kHz) respectively. (*iii*) Characterization of Tm:YAG laser, diode-pumped Tm-Ho:YAG, and Tm-Ho:KYF. To optimize all of these oscillators, particular emphasis was placed on accurate measurements of amplitude and frequency fluctuations, and the analysis of the various noise sources. Ultimately, several frequency noise measurement methods, based on error signal analysis of a control loop or beat signals at optical frequencies, have been successfully deployed.

The significant aspect in noise characterization of these solid state laser oscillators is the need to use high resolution measurement methods to reveal the low noise of amplitude and frequency of optical sources and use of specific temporal variances for the study of instability of frequency in the medium and long term. To this end, interferometric measurement systems of an optical signal phase fluctuations for increased amplitude noise rejection, employing differential detection techniques and pecific experimental equipment, have been studied and designed. Using a general analytical discussion, and with hints of originality compared to previous works in literature, Prof. Svelto has proved that one can improve the signal-to-noise ratio or increase the sensitivity of the phase discriminator by adopting special precautions in measurement setup.

4. Collaboration for international projects aimed at the development and characterization of samples of wavelength in the spectral region of 1.5 μm

Internationally, due to the emergence of WDM optical communications and HD-WDM in the last decade, seeking a *standard* spectral region of 1.5 μm wavelength has become an important subject of scientific research. Several samples, with different characteristics of accuracy and stability, are at an advanced stage of study and experimentation for both field and laboratory for metrology studies. In this area, due to the professional advancements in the field of frequency stabilization of lasers in 1.5 μm and construction and characterization of optical sources with high efficiency and spectral purity, it was possible to start important scientific collaborations and exchanges with research institutions well known internationally such as:

• *National Research Laboratory of Metrology* in Tsukuba, Japan (Dr. Atsushi Onae): Research aimed at studying, development and characterization of a sample of wavelength at 1.5 μm based on saturated transitions of acetylene molecule ($^{13}C_2H_2$) with metrological characteristics (frequency stability of ~10^{-12} with an accuracy of reference transitions better than 10^{-10}).

• *Laser Zentrum Hannover* in Hannover, Germany (Dr. Ingo Freitag): Research aimed at studying, development and characterization of amplitude and frequency of new highly stable laser sources for applications in optical measurements at very high resolution (*high-resolution spectroscopy, gravitational wave detection, optical radars, etc.*) and for LIDAR applications (Tm:YAG NPRO).

• *Department of Electrical Engineering – Physical Electronics Tel-Aviv University* in Tel-Aviv, Israel (Prof. Ady Arie): Research aimed at studying, development and characterization of absolute frequency references at 1.5 μm wavelength, based on using 1540-1556 nm laser frequencies for frequency doubling and locking to saturated atomic transitions (^{39}K and Rb). Wavelength references in this way achieved (frequency stability of $<10^{-12}$ and $\sim10^{-13}$ with accuracies of 1.3×10^{-6} and 1.3×10^{-11}, respectively in the two cases) will allow comparisons and calibrations with other international standards in this important spectral region. In particular, the optical frequency standard based on the two-photons transition of Rubidium atom ($\lambda\cong778$ nm and $\Delta\nu\sim300$ kHz) could be the best achievement of frequency standards in this spectral region.

Electronic Measurement Instrumentation

1. Design and implementation of electronic measurement instrumentation

Electronic instruments with advanced features and/or properties have been designed, developed and characterized for different experiments and ongoing research programs such as: (*a*) Transimpedance Amplifiers for Photodetectors with low noise characteristics with a bandwidth from 100 kHz to 100 MHz; (*b*) a fully-functional analog ratio-meter; (*c*) a fully analog frequency-to-voltage converter with bandwidth 500 kHz to 50 MHz, with measurement time of less than 50μs. The bandwidth of this F/V converter is far superior to what is achievable with commercially available instruments. (*d*) Particular attention has also been devoted to the development of a prototype laser diode controller/power supply. The experimental tests have shown that these power supplies are designed to work with a direct current polarization of up to 10 A offering a high bandwidth (4 MHz) and dynamic (±1 A) analogue modulation. In addition the instrument presents a modest amplitude noise (*ripple*< 0.5% at full current) and offers the possibility of an active stabilization of the operating temperature of the laser diode (within 0.05° C).

In addition, a system for measurement of phase noise in frequency multiplied oscillators (typical *clock* signal for telecommunication networks) with high resolution and a background of noise of -150 dBc was designed and developed. A full band from 100 MHz to 5.4 GHz, by frequency multiplication with low phase noise, was also made available: the oscillating signal obtained at 5.4 GHz will be employed for the excitement of a resonant cavity microwave and optical frequencies simultaneously (OFCG, *Optical Frequency Comb Generator*). The significant aspect of these experiments was the design and implementation of multiplier consisting of a diode followed by a linear amplifier for measuring low noise. This system uses multiplication schemes that have been fully tested at frequencies of the order of tens of megahertz and can reach beyond 100 MHz unlike no other system previously available.

As part of a research collaboration with researchers from the University of Pisa, an electronic equipment with high spectral purity (72 GHz oscillator) was developed for the characterization of ultrafast optical detectors.

As part of a scientific collaboration with the IEN Galileo Ferraris, digital frequency synthesizers have been developed with high accuracy for the measurement of low frequency impedance on amplitude levels.

Prof. Svelto has also designed and developed precision thermometers, both analog and digital (4.5 digits), based on the Platinum resistive sensors. These instruments offer a high resolution *display* of 1mK and ensure accuracy of 0.05 K around room temperature. Regarding resolution and accuracy of the measurement, these thermometers have been verified to approach the performance of much more expensive secondary calibration laboratory instruments.

2. Measurements on high-voltage signals

Issues relating to measurements on high-voltage signals were studied by scientific collaboration with colleagues in the Department of electrical engineering of the Politecnico di Milano. In particular, an original solution to the problem of measuring high voltage network signals has been proposed and developed. The solution consists of the development of optoelectronic measurement systems capable of transferring high voltage signals by feeding optical energy to the transducer. The prototype provides an accurate digital and broadband measurement, up to 40^{th} harmonic of the fundamental frequency, with an excellent galvanic separation of the low voltage measurement section. The particularity remotely feeded optical sensor type allows this work to be framed as a pilot study and feasibility study for high performance systems demonstrator where galvanic isolation is a key requirement. Also in the framework of high-voltage measurements, metrological characterization was performed by a current-voltage transducer based on Rogowski coil.

3. Electrical characterization of acoustic intra-cochlear stimulators and interaction between the electrical signal and biological tissue

In collaboration with fellow researchers of the center of biomedical engineering of the CNR and Audiological Foundation of Varese, the functional characteristics of cochlear stimulators were studied and measured. Although cochlear implants are a well-established technology since almost twenty years, in clinical practice the information about the morphology and characteristics of electrical impulses generated by each electrode are given only in the manuals supplied by the manufacturers. A current pulse acquisition system supplied by cochlear implant was developed in order to verify experimentally the characteristics of impulses to different acoustic stimulator electrodes. A 3D model of the cochlea was then developed and numerical simulations were conducted to calculate the electrical potentials produced in different sections of the organ as a function of impulses sent to the cochlear implant. To validate the theoretical model an experimental apparatus is then created for measuring an analysis *in vitro* (saline solution) of the spatial distribution of the electric field within the cochlea.

Data Acquisition, Image Processing and Analysis

1. Design and development of automated measurement systems for acquisition and processing of digital data

Digital measurement, and subsequent *DSP* (*Digital Signal Processing*) of physical quantities is an important scope of modern measuring instruments and statistical analysis techniques. In this area, specific digital systems to characterize the discharge process controlled by button batteries for biomedical devices have been designed and developed in the Laboratory directed by Prof. Svelto. The following data acquisition systems were subsequently developed and used to record measurement signals:

- A data acquisition card with four A/D channels was specifically designed to run on PC ISA bus, for simple measurements of electrical signals in the laboratory (measurements of transfer functions of electronic controls, temperature monitoring of multiple objects, acquiring multiple physical quantities of influence/control). Similarly, a single-channel A/D capture card and 16 *bit* was also specially designed for the PC ISA bus, for high-resolution laboratory measurements.
- A non-proprietary system was incorporated to capture 128 channels, with 12 *bit* A/D converter, dedicated to monitoring multiple processes of button batteries. The measuring *software*, specially developed for Windows™, allows to detect and compensate for the resistance series (contacts and switches and any load resistance) of each circuit. Moreover, it is integrated in a control circuit to select three different kinds

of load (*e.g.* "open", "current", and "high power"). The speed performance of this system is modest, but allows fully automated handling of the measurement process while maintaining good performance measurement characteristics of the obtained samples and the statistical analysis results enabling high ease of use. The work, carried out under a research contract (7/30/1997) with the firm Amplifon S.p.A. entitled "Misure di scarica controllata per la stima dei tempi di vita in pile per applicazioni bioacustiche" has resulted in the first measurement system in Italy for more than 100 simultaneous automated analysis button batteries for hearing aids.

• Two acquisition cards with four A/D channels and 16 *bit* (ADS7825P converter) with good linearity over a range of ± V-8 with a *bit* equivalent of 13 (maximum noise level of 1.5 mV) were designed. For this system, a custom measurement software (Visual Basic™ and *routine* C^{++}) was developed which displays the oscillographic signal format and a plot of the spectral analysis (FFT) almost in real time. This system has allowed the creation of a simple and versatile oscilloscope and spectrum analyzer based on non-proprietary *hardware* and *software*. Afterwards, these two cards have been incorporated with a switching system on different input and measuring impedances, PC controlled, timing and transient discharge button cells. The work, carried out under a research contract with the company Varta S.p.A. entitled "Analisi qualitativa di pile per apparecchi biomedicali", has enabled the characterization and intercomparison of performances of batteries commercially available for the specific audio application.

2. Development and validation of 3D profilometry techniques of anatomical parts and digital image processing

In collaboration with researchers of the center of biomedical engineering of CNR, 3D objects using laser scanning measurement systems and corresponding image recording and processing were developed and characterized. In particular a simple system for laser scanning, with visible light has been studied and developed to measure the surface and then to perform registration and processing of the image originally acquired from two different views (cameras). By combining data of cameras and reconstructing the points recorded, a 3D model of the area of investigation for objects of arbitrary shape was reconstructed which comprised a volume of $30\text{x}30\times30\ \text{cm}^3$. The experimental validation of the new measuring system has led to satisfactory results and meets the metrological requirements of specific biomedical measurement systems. The new proposed methodology for image reconstruction led to the use of the measuring system in both academic and commercial applications of interest.

3. Study and realization of electro-optical system for measuring Particle Image Velocimetry (PIV)

In collaboration, within the Politecnico di Milano, with colleagues in the Department of hydraulic engineering and Aerospace Engineering Department, measuring systems have been developed to characterize the speed profile of a fluid (both liquid and gaseous). The new instrumentation proposed allows the measurement of PIV (*Particle Image Velocimetry*), through a scene illuminated with pulsed lamps in three different colors and the resulting scanned images after processing, determine the evolution of the spatial position of the individual particles in the fluid. With the new instrument, the flow field inside a water channel could be analyzed experimentally when an obstacle was present in the stream in the laboratory of hydraulic engineering (proposed application to emulate and measure the speed profile of water which might overflow a dam and eventually overwhelms residential areas). Recently the tri-color measurement method and the proposed system were also applied to study the air turbulence around the wing of a plane, in the Department of aerospace engineering.

Other Research and Development

As a part of scientific collaboration with colleagues in the Physics Department of Politecnico di Milano, Prof. Svelto took part in the contract (two years, from January 1996) at ESA-ESTEC *Nr. 91/91/9553/NL/PB (SC) phases 1 and 2*, the European Space Agency, entitled "Studies and LIDAR breadboarding of critical technologies". For this contract prefeasibility studies have been performed by an optical oscillator with high consistency for LIDAR-Doppler and transmitter-receiver system measurements. On the basis of design specifications: possible methods to obtain the values such as levels of accuracy and frequency stability of the oscillator, optoelectronic measuring systems, modulation and frequency conversion for the compensation of the Doppler Effect due to the relative Earth-satellite motion were examined. Other aprties involved in this program are: the French companies Aerospatiale and Quantel, ETH Zürich, Alenia and the Fondazione Ugo Bordoni.

Within an international *network* of optical frequency metrology and in collaboration with Japanese and Israeli research institutions, several wavelength standards in the spectral region of 1.5 μm using atomic and molecular frequency references (after duplication frequency in non-linear crystals) based on saturated absorption lines were developed. The experience achieved in this area and measurements of high purity spectral characterization of laser oscillators has allowed Prof. Svelto to take part in a European research project, within the 5th framework programme of the European Community, entitled "*Certified REference materials for optical telecommunication Wavelengths* (CREW)". In this project, coordinated by Prof. Svelto on the Italian side, the Research unit of Politecnico di Milano has experienced several high resolution laser spectroscopy techniques using molecular species of use not as common as frequency references at 1.5 μm.

List of Scientific Publications

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