Menlo Systems went on tour to three national metrology institutes (NMIs) to demonstrate the capability of the SmartComb for laser calibration. The device was boxed up, and driven 1500 km from Munich to Vienna to Bratislava to Prague and back. A total of five metrology lasers were calibrated during the tour.

### COUNTRY | INSTITUTE | LASER TYPE
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![Austria Flag] | BEV, Vienna | Präzisions-Messtechnik Iodine-stabilized HeNe
![Austria Flag] | BEV, Vienna | Winters Model 100 Iodine-stabilized HeNe
![Slovakia Flag] | SMU, Bratislava | Agilent 5519B Zeeman-stabilized HeNe
![Czechia Flag] | CMI, Prague | CMI Iodine-stabilized HeNe (f and d transitions)
![Czechia Flag] | CMI, Prague | Acetylene-stabilized DFB laser at 1542 nm
The definition of the meter has been realized via iodine-stabilized Helium-Neon lasers over the past few decades [1]. NMI's worldwide use these lasers either directly in interferometric length measurements, or they are used to calibrate other commercial and cheaper lasers, such as Zeeman-stabilized Helium-Neon lasers. Several transitions in $^{127}$I$_2$ (iodine) vapor overlap with the 1 GHz gain band of the Helium-Neon gas mixture, and preferably the $a_{16}$ or "f" component of the R(127) 11-5 transition is used to define the meter. Since this stabilized laser frequency can drift a few kHz over several months, it is necessary to have comparisons and calibrate the absolute value. Optical frequency combs have been used for almost two decades to measure the frequency against the SI-unit of the second, by locking the comb to a Cesium clock.

Recent advances in frequency comb technology at Menlo Systems have shrunk the size from complicated frequency chains that required an entire optical lab in the 1990s, to Ti:Sapphire based combs, to fiber-based combs, all the way to a compact 19" 3U SmartComb device including all electronics and optics necessary for measurement of the 633 nm light from such a Helium-Neon laser.

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**FIRST STOP: VIENNA**

The first stop of the SmartComb Tour was BEV in Vienna (Bundesamt für Eich- und Vermessungswesen). Dr. Michael Matus and his colleagues started out with the first commercial Ti:Sapphire comb from Menlo Systems back in 2002, followed by nearly ten years of using an FC1500-250 from Menlo Systems to regularly calibrate Helium-Neon lasers. Their two commercial iodine-stabilized Helium-Neon lasers were measured (Präzisions-Messtechnik Dr. Ulrich Hoppe PMT-HE-96 "BEV-1", and Winters Electro-Optics Model 100 "BEV-2"). The SmartComb was connected to the local 10 MHz Hydrogen Maser reference, which is regularly calibrated against their Cesium clock. A measurement was conducted over 16 hours over night on BEV-1 as shown in Fig. 1. The result showed +3.088(27) kHz as compared to the recommended value of 473 612 353 604 kHz, which had previously been confirmed in a measurement using the FC1500-250 resulting in +3.139(75) kHz. A similar measurement was conducted on BEV-2 over a 70-minute measurement of the transition, confirming the previously measured value.

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**SIXTEEN HOUR MEASUREMENT OF BEV-1 f-TRANSITION**

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**Fig. 1:** Left: Raw data, Right: Allan Deviation
Dr. Roman Fira has been working in length metrology for many years at the Slovak Institute of Metrology (SMU, Bratislava). Since their Winters Model 100 iodine-stabilized laser was currently being refurbished, instead a direct measurement of a Zeeman-stabilized Helium-Neon laser was conducted (Agilent 5519B). This laser is well-known in commercial interferometers, and direct calibration could be very convenient. The 6 mm wide beam was coupled into a single-mode PM fiber, and then directly connected to the SmartComb. The proof-of-principle demonstration was limited by the stable quartz which was used as a 10 MHz reference, since the Cesium clock was not available. Nonetheless we could confirm the previously calibrated value which was performed several years earlier against an iodine-stabilized HeNe laser. The SmartComb made the measurement so easy, that the intermediate step of measuring a beat with a laser which itself is calibrated to the comb is unnecessary. Plugging into the SmartComb and measuring only takes a few minutes, making these extra steps unnecessary. Prior knowledge of the laser frequency to 50 MHz allows a direct measurement using the SmartComb. Alternatively, the mode number that is being used for the measurement can be determined using a wavemeter or the SmartComb itself by measuring with two different repetition rates and solving for the mode number \( n \) [2].

Finally, the SmartComb was used in two labs at the Czech Metrology Institute (CMI, Prague) under the supervision of Dr. Petr Balling. A homebuilt Iodine-stabilized Helium-Neon laser was set to the f-transition, and later to the d-transition as a second test. The SmartComb was referenced to a stable Rubidium-clock, which is disciplined to GPS for long-term stability and traceability to the SI second. The offset from the recommended value was identical to that measured with Dr. Balling’s Ti:Sapphire frequency comb from Menlo Systems. The fifth metrology laser to be measured was a \( ^{13}\text{C}_2\text{H}_2 \) (acetylene)-stabilized DFB laser at 1542 nm. The Erbium femtosecond laser in the SmartComb has fundamental light at this wavelength, so simply plugging in the fiber resulted in a strong beat that could be counted as shown in Fig. 2. The recommended value for such a stabilized laser is 194 369 569 384 kHz [3]. The calibration showed a tiny offset of -1.918(207) kHz from this value in literature, thereby demonstrating the SmartComb capabilities and the fiber laser performance.

**SECOND STOP: BRATISLAVA**

**THIRD STOP: PRAGUE**

**MEASUREMENT OF ACETYLENE-STABILIZED DFB LASER**

**Fig. 2:** Left: Raw data, Right: Allan Deviation
The first few visits have shown that the SmartComb is a versatile and robust tool, that makes calibration of lasers as easy as using a wavemeter, nevertheless providing a direct link to the SI second. Simply plug in a fiber-coupled laser, and start the calibration measurement. Rough roads and a night in the 5°C car didn’t harm the SmartComb at all. Please contact us to have a live demonstration in your lab.

Fig. 3: The SmartComb in the labs of:
Dr. Michael Matus at BEV in Vienna (left), Dr. Roman Fira at SMU in Bratislava (middle), and Dr. Petr Balling at CMI in Prague (right).

**PUBLICATIONS**


**WEBLINKS**

Institutes websites:

BEV in Vienna (Bundesamt für Eich- und Vermessungswesen)  www.bev.gv.at

Slovak Institute of Metrology (SMU, Bratislava)  www.smu.sk

Czech Metrology Institute (CMI, Prague)  www.cmi.cz

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