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Permanent Link to MEMS oscillators on the move

2021/05/18

Advances in micro-electro-mechanical systems (MEMS) sensor technology include temperature-sensing MEMS oscillators (TSMO). Pairing a TSMO with a GNSS receiver, the authors successfully performed carrier-phase positioning and obtained accuracies better than typically required for automotive applications. MEMS oscillators can present space and cost advantages in integrated circuit assembly. By Bernhard M. Aumayer and Mark G. Petovello MEMS oscillators have found their way into the electronics industry and are on their way to enter a multi-billion consumer devices market, which is currently dominated by crystal-based oscillators. One technology review concluded that MEMS oscillators fill the gap between high-performance quartz and low-performance LC (inductor+capacitor) oscillators while allowing for better system and package integration. Nevertheless, due to stringent requirements on frequency accuracy and phase noise, MEMS oscillators have not yet been integrated in GNSS receivers. In earlier research, we demonstrated the feasibility of using a temperature-sensing MEMS oscillator (TSMO) in a software receiver, operated over the full industrial temperature range (–40° to +85° C) for pseudorange (code) positioning. However, high-accuracy carrier-phase positioning techniques require uninterrupted carrier-phase tracking, producing more challenging requirements for the receiver's oscillator. Here, we extend that research to demonstrate the feasibility of using a TSMO for carrier-phase positioning. Background The MEMS resonator used here has an approximately 150 ppm frequency drift over the temperature range of –40° to +85° C, which is about three to five times greater compared to a standard crystal. The integrated temperature sensor provides very good thermal coupling with the resonator, enabling accurate frequency estimation once the frequency versus temperature function (FT polynomial) is estimated. This FT polynomial can be estimated by periodically measuring the frequency and temperature at different temperatures, and fitting the FT polynomial to the measurements. After this calibration stage, the oscillator frequency error can be estimated using the temperature measurement and the polynomial only. This frequency error can aid the GNSS receiver for acquiring and tracking signals. As the temperature measurements are affected by noise — which is also amplified by the FT

polynomial, producing frequency noise in the receiver — the temperature measurements can be filtered accordingly to reduce noise. Methodology Temperature compensation of the oscillator frequency can be beneficial in scenarios with fast changes in temperature (and therefore fast changes in frequency) or when operating the oscillator at extreme temperatures, where temperature sensitivity is more pronounced. The TSMO implements an onchip integrated temperature sensor in close proximity to the resonator and provides an accurate estimate of its temperature. We first examine more complex and non-real-time capable filters to assess performance improvement and limits of bandwidth reduction. For the second part of this research, where the TSMO based GNSS receiver's measurements are used for RTK positioning, none of the conditions requiring temperature compensation (fast changes or extreme temperatures) are met, and therefore temperature compensation was not applied. Temperature Measurements Filtering. When temperature compensation is applied, filtering of the chip-integrated temperature sensor measurements is performed to reduce measurement noise introduced by the temperature measurement circuit. As the signal frequency and phase from the satellite can — under negligible ionospheric scintillation conditions — be assumed significantly more accurate and stable than the local oscillator's carrier replica, common errors in the received signals' carrier frequencies can predominantly be accredited to the local oscillator. Therefore, under the condition of a defined tracking loop, estimated frequency accuracy and phase tracking stability are suitable measures of the local oscillator's short-term frequency and phase stability, as well as the influence of the temperature compensation. The temperature compensation method is being digitally applied to the digitized IF signal as a first stage in the software receiver (Figure 1). For generating this signal, a filtered version of the raw temperature measurements is generated and a function (temperature compensation or FT polynomial) to convert those temperature measurements to local oscillator frequency estimates is applied. Figure 1. Temperature compensation and signal processing structure. The digitized IF samples of the received signal as well as the frequency estimates from the temperature measurements are then processed by the GSNRx software GNSS receiver developed at the University of Calgary. Satellite-specific phase-lock indicators (PLI) as well as the receiver's clock-drift estimates are extracted and analyzed, and compared to the results from other filter implementations. The temperature filters are designed as a combination of variable length finite impulse response (FIR) filters and 1-tap inifinite impulse response (IIR) filters, as this design yields a reasonable trade-off between high stop-band attenuation, small group delay, low complexity and high filter stability. Although feasible in hardware implementations, multi-rate filtering approaches were not investigated. The filters used are summarized in Table 1, where filters #1 and #2 were used in our previous research. In the table, BC denotes a box-car FIR filter implementation, and BW refers to an approximated brick-wall filter (truncated sinc in time domain). Although the order of the filter is higher, all feedback coefficients (an) other than the first a1 are zero for stability reasons. The stated bandwidth is the 3 dB bandwidth of the filter, (fwd/bwd) indicates forward and backward filtering, and GDC indicates group delay compensation. Table 1. Filter implementations for temperature measurements. Carrier-phase positioning. It is well known that carrier-phase measurements can deliver much higher accuracy positions than pseudorange measurements. The challenge for MEMS oscillators is to mitigate

the phase noise of the resonator, and any noise resulting from temperature compensation, to allow continuous phase tracking. Failure to do this will result in more cycle slips, which in turn will limit the benefits of using carrier-phase measurements (since the navigation filter will have to more frequently re-estimate the carrier-phase ambiguities). Testing The static data set collected in our earlier research was reused for this work. The data was collected from a static rooftop antenna, while the TSMO was placed inside a temperature chamber, which was performing a temperature cycle from +85° to –30° C and back up to +60° C. The temperature compensation polynomial (Figure 1) was fit using the clock drift estimate from running the software receiver with the same data set without any temperature compensation. The temperature filters in Table 1 were then applied to the raw temperature measurements, and processed with the same software receiver as in our earlier work, allowing for direct comparison of the results. Carrier-phase positioning. To mitigate effects from orbit and atmospheric errors, first a zero-baseline test was carried out on a rooftop antenna on the CCIT building at the University of Calgary. Two identical IF sampling front-ends with a sampling rate of 10 MHz were used for each of the tests, one utilizing a built-in TCXO and the other using the external MEMS oscillator clock signal. A commercial GNSS receiver was used as a static base for this setup. The TSMO and TCXO based front-ends were used as a rover, all connected to the same antenna. For all tests, only GPS L1 C/A signals were used by the devices under test. Second, a short-baseline test utilizing two antennas about 2.5 m apart was carried out, with the same equipment. For reference, surveyed coordinates of the antennas' base mounts were used. For these two tests, the front-ends and oscillators were at constant temperature (to within variation of room temperature) on a desk. Third, two road tests in a car driving around Springbank airport close to Calgary were performed. One test involved smooth driving only, and the second test was performed by rough driving over uneven roads so that higher accelerations on the oscillators were provoked. To allow a performance comparison between the TCXO and TSMO based receivers, the two front-ends were used as rover receivers at the same time and were connected to the same geodetic-grade antenna mounted on the vehicle's roof. Equipment and processing. All samples from the IF-sampling front-ends were processed with the University of Calgary's GSNRx software GNSS receiver to obtain code and carrier phase as well as Doppler measurements. These measurements were subsequently processed with the University of Calgary's PLANSoft GNSS differential real-time kinematic (RTK) software to obtain a carrier-phase navigation solution. As a reference, a commercial GNSS/INS system using a tactical-grade IMU was used. The dual-frequency, multi-GNSS, carrier-phase post-processing of the reference data provided a reference position of better than 1 cm estimated standard deviation in all three axes, which is in the following referred to as "truth." The kinematic tests were carried out with the PLAN group's test vehicle, a GMC Acadia SUV-style vehicle. A geodetic-grade antenna was mounted in close vicinity to the LCI tactical-grade IMU as shown in Figure 2. The antenna was split to a reference receiver and the two IF-sampling front-ends. The front-ends were rigidly mounted to each other as well as to the TSMO board to ensure similar accelerations on both oscillators. The front-ends were placed in the center of the passenger cabin. Figure 2. Equipment setup on PLAN group's test vehicle. The kinematic tests were performed near the Springbank airport close to Calgary, Alberta. For a base station,

a commercial dual-frequency receiver was set up on an Alberta Survey Control Marker with surveyed coordinates. A leveled antenna was used with this receiver, and 20 Hz GPS and GLONASS raw measurements were collected to provide a base for both the reference receiver and the receivers under test. Results First, we compared results from improved temperature filtering to results from our earlier work. The performance of temperature measurement filtering is quantified with regard to frequency accuracy (mainly arising from filter group delay) and phase-lock indicator values of the tracked signals, which are mainly deteriorated from noise introduced by temperature compensation. The best performance with regard to PLI (Figure 3) was achieved using the forward-backward 1-tap IIR filter (#4 in Table 1). Figure 3. Cumulative histogram of PLI with temperature compensation. While the estimation error introduced by this low-bandwidth and high group delay filter was significant especially at fast temperature changes before and after the temperature turnaround point at 2067 s into the run (Figures 4 and 5), the forward-backward filtering cancels a major part of that delay. Note that this filter has even lower bandwidth (Table 1) than the same filter used in forward-only filtering, as the resulting magnitude response squares with the forward-backward filtering approach. Figure 4. Temperature-based estimation of oscillator error. Figure 5. Error in temperature-based estimation of oscillator error (note the larger error due to filter delay). Only a slight performance decrease can be seen when using a boxcar filter with 2048 taps, but only when compensating for the FIR part's known group delay of approximately 1 s. It is noted that filters #4 and #6 — which show best performance — are only usable in post-processing or with significant latency. In contrast to group-delay compensated filters, which might not be applicable in low-latency, real-time applications, the even lower bandwidth 1-tap IIR filter — although introducing a still significant group delay — resulted in best tracking performance amongst the filters, which are not compensated for any group delay. This filter's performance is surprisingly followed by the low-complexity 1-tap IIR filter (#3) ahead of the filters implementing the boxcar (#5) or brickwall (#7) filter blocks. The reasoning for this lower performance — given the results of the equal coefficients but group delay compensated filter (#6) performance — can be found in the higher delay of the measurements compared to the group delay compensated filter. The difference between boxcar and brickwall filter was found to be negligible with this data set. In general, the receiver was able to provide very good carrier-phase tracking using all of the proposed filters. The satellite signals were tracked with a PLI of better than 0.86 between 98 to 99.8 percent of the time, depending on the implemented filter; this corresponds to approximately 30 degrees phase error or 2 cm ranging error at the L1 frequency. Short baseline test. Both receivers correctly fixed the ambiguities within 150 s, kept the ambiguities fixed until the end of the data set, and computed the correct position with an estimated accuracy of better than 1 cm in each axis. The position estimate error is comparable between the two receivers, and slightly higher than in the zero-baseline test because multipath errors are no longer removed. Figure 6 shows the position estimates errors for both receivers. No significant systematic errors are evident in the position errors from these tests. The slowly varying error in height is typical for multipath signals. Figure 6. Short baseline position estimates error for TSMO (top) and TCXO (bottom) based receivers. The color bar at the bottom denotes the ambiguity status: all fixed ambiguities (green),

partially fixed ambiguities (yellow) and float-only ambiguities (red). The double-differenced phase residuals are slightly higher for both receivers than in the zero-baseline test (not shown), but follow the same trend for both receivers and are therefore accredited to the signals or processing software rather than to the oscillator. The phase-lock indicator values for all satellites are visualized in a cumulative histogram in Figure 7. Because the TSMO based receiver's PLI values are on average slightly smaller than for the TCXO based receiver, higher noise is expected in those measurements. Nevertheless, in the processed data sets, this has no significant effect on the estimated position. Figure 7. Cumulative histogram of PLI values for TSMO and TCXO-based receivers in short baseline test. Kinematic Tests The first test was performed on paved rural roads. Any road unevenness was avoided where possible, or driven over fairly slowly where unavoidable. The test started with an approximate 150 s static time to assure initial fixing of the ambiguities, and continued with driving in open-sky and occasional foliage environment. As visualized in Figure 8, both receivers were able to fix the ambiguities correctly within roughly 30 s. During the test, both receivers fell back to partially fixed or float ambiguities. The TCXO based receiver computes a partially fixed solution between 650 s and 1200 s, as apparent from the position errors in Figure 8. In the same interval, the TSMO based receiver computes a float-only solution. Figure 8. Smooth driving road test position estimates error for TSMO (top) and TCXO (bottom) based receivers. Bumpy Driving. The second test route was chosen to include several locations of road unevenness and a slightly elevated bridge (bump) over a small stream, which was driven over at five different speeds, ranging from approximately 20 to 74 km/h. Both receivers were able to compute a sub-meter accurate position during the entire test. While the TCXO based receiver was able to compute a fixed ambiguity position with centimeter-level accuracy during the majority of the test, the TSMO based receiver was able to fix the ambiguities at significantly fewer epochs and reverted to a float ambiguity most of the time, decreasing positioning accuracy to the decimeter-level. From Figures 9 and 10 the times of higher acceleration (>5 m/s) when driving over the bridge (between 260 and 490 s into the test) correlate well with the times of reduced number of fixed ambiguities, and therefore times where the navigation engine is reverting to a float ambiguity carrier-phase solution. Figure 9. Bumpy driving road test position estimates error for TSMO (top) and TCXO (bottom) based receivers. 5 m/s) accelerations for TCXO based receiver. Source: Bernhard M. Aumayer and Mark G. Petovello" width="600" height="308" srcset="https://www.gpsworld.com/wp-content/uploads/2016/01/Fig-10.jpg 600w, https://www.gpsworld.com/wp-content/uploads/2016/01/Fig-10-250x128.jpg 250w, https://www.gpsworld.com/wp-content/uploads/2016/01/Fig-10-300x154.jpg 300w" sizes="(max-width: 600px) 100vw, 600px" />Figure 10. Bumpy driving road test number of total and used satellites, and vehicle excess (>5 m/s) accelerations for TCXO based receiver. At approximately 562 s into the test, the vehicle hit a larger puddle on the dirt road resulting in high vertical acceleration (> 1g). Despite this high acceleration, the TCXO based receiver stayed in fixed ambiguity resolution mode, and the TSMO based receiver continued in partially fixed ambiguity solution mode. At 875 s into the test, the car passed underneath two separated two-lane highway bridges, which led to a loss of all signals on all receivers, including the reference receiver. Both receivers reacquired the signals after the underpass and

fixed the ambiguities again after approximately 100 s. Conclusion Temperature-measurement filter implementations were presented that outperform the previous low-complexity implementations, but at the cost of higher computational requirements, more latency or even real-time capability because of the more complex design or non-causal filtering approach. Using the proposed filtering approach, the eight strongest satellites were tracked in phase-lock tracking state for 98–99.8 percent of the test time, while performing a full hot-cold temperature cycle. Furthermore, we showed the performance of traditional double-differenced carrier-phase positioning using a receiver with a temperature-sensing MEMS oscillator. Static and kinematic tests were performed, and the operation of an otherwise identical TCXO based receiver at the same time allowed to compare the oscillator's performance in several environments as well as their sensitivity to accelerations. Carrier-phase positioning with TSMO based GNSS receivers was possible with accuracies better than typically required for automotive applications. Manufacturers The temperature-sensing MEMS oscillator was produced by Sand 9, which has been acquired by Analog Devices, Inc. A NovAtel 701GG geodetic-grade antenna was mounted on the test vehicle and a NovAtel SPAN-SE was the reference receiver. A NovAtel ProPak-V3 was the base station, with a Trimble Zephyr antenna. Bernhard M. Aumayer is a Ph.D. candidate in the Position, Location and Navigation (PLAN) Group in the Department of Geomatics Engineering at the University of Calgary. He worked for several years as a software design engineer in GNSS related R&D at u-blox AG. Mark Petovello is a professor in the PLAN Group, University of Calgary. His current research focuses on software-based GNSS receiver development and integration of GNSS with a variety of other sensors. This article is based on a technical paper presented at the 2015 ION-GNSS+ conference in Tampa, Florida.

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A constantly changing so-called next code is transmitted from the transmitter to the receiver for verification,this jammer jams the downlinks frequencies of the global mobile communication band- gsm900 mhz and the digital cellular band-dcs 1800mhz using noise extracted from the environment,three phase fault analysis with auto reset for temporary fault and trip for permanent fault,energy is transferred from the transmitter to the receiver using the mutual inductance principle,6 different bands (with 2 additinal bands in option)modular protection.it detects the transmission signals of four different bandwidths simultaneously,in contrast to less complex jamming systems,are freely selectable or are used according to the system analysis,this paper shows a converter that converts the single-phase supply into a three-phase supply using thyristors.9 v block battery or external adapter.with the antenna placed on top of the car,here is the circuit showing a smoke detector alarm.with its highest output power of 8 watt.it has the power-line data communication circuit and uses ac power line to send operational status and to receive necessary control signals,pll synthesizedband capacity,this paper shows the controlling of electrical devices from an android phone using an app,ii mobile jammermobile jammer is used to prevent mobile phones from receiving or transmitting signals with the base station,the operating range does not present the same problem as in high mountains.so that the jamming signal is more than 200

times stronger than the communication link signal.normally he does not check afterwards if the doors are really locked or not,this system also records the message if the user wants to leave any message,the scope of this paper is to implement data communication using existing power lines in the vicinity with the help of x10 modules.provided there is no hand over.from the smallest compact unit in a portable,the light intensity of the room is measured by the ldr sensor,40 w for each single frequency band,by activating the pki 6100 jammer any incoming calls will be blocked and calls in progress will be cut off.

Scada for remote industrial plant operation.we would shield the used means of communication from the jamming range.i introductioncell phones are everywhere these days.when the brake is applied green led starts glowing and the piezo buzzer rings for a while if the brake is in good condition.auto no break power supply control,mobile jammer can be used in practically any location,soft starter for 3 phase induction motor using microcontroller.the frequencies extractable this way can be used for your own task forces.the present circuit employs a 555 timer,automatic telephone answering machine.we then need information about the existing infrastructure.this is done using igbt/mosfet,this also alerts the user by ringing an alarm when the real-time conditions go beyond the threshold values.although industrial noise is random and unpredictable,the zener diode avalanche serves the noise requirement when jammer is used in an extremely silet environment,wireless mobile battery charger circuit.radio transmission on the shortwave band allows for long ranges and is thus also possible across borders,many businesses such as theaters and restaurants are trying to change the laws in order to give their patrons better experience instead of being consistently interrupted by cell phone ring tones,smoke detector alarm circuit,5% to 90%the pki 6200 protects private information and supports cell phone restrictions.here is the circuit showing a smoke detector alarm,depending on the already available security systems,which is used to test the insulation of electronic devices such as transformers.detector for complete security systemsnew solution for prison management and other sensitive areascomplements products out of our range to one automatic systemcompatible with every pc supported security systemthe pki 6100 cellular phone jammer is designed for prevention of acts of terrorism such as remotely trigged explosives.overload protection of transformer,temperature controlled system.one of the important sub-channel on the bcch channel includes.

The unit requires a 24 v power supply,arduino are used for communication between the pc and the motor,accordingly the lights are switched on and off,this article shows the circuits for converting small voltage to higher voltage that is 6v dc to 12v but with a lower current rating,high voltage generation by using cockcroft-walton multiplier.a mobile phone might evade jamming due to the following reason,automatic power switching from 100 to 240 vac 50/60 hz,the marx principle used in this project can generate the pulse in the range of kv,as overload may damage the transformer it is necessary to protect the transformer from an overload condition.power grid control through pc scada,clean probes were used and the time and voltage divisions were properly set to ensure the required output signal was visible.6 different bands (with 2 additinal bands in option)modular protection.access

to the original key is only needed for a short moment,2 – 30 m (the signal must < -80 db in the location)size..

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