Gravitational Waves Detection System

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The system which will be described in the following has been designed for detecting tiny changes in the Earth's gravitational field. In particular it aims at detecting travelling spacetime curvatures. The working principle is based on General Relativity which relates gravity changes to changes of timeflow. A well known experiment that confirmed the mentioned relationship between gravity and time, which had been predicted by Albert Einstein in his General Relativity Theory, was performed by Hafele and Keating in October 1971, see the related reports in the Internet.

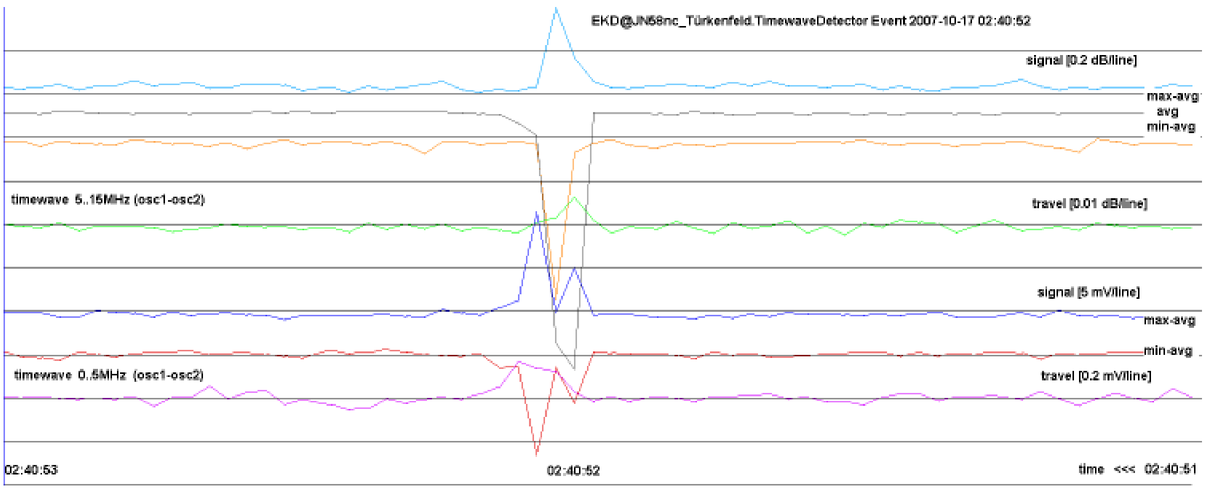
The idea

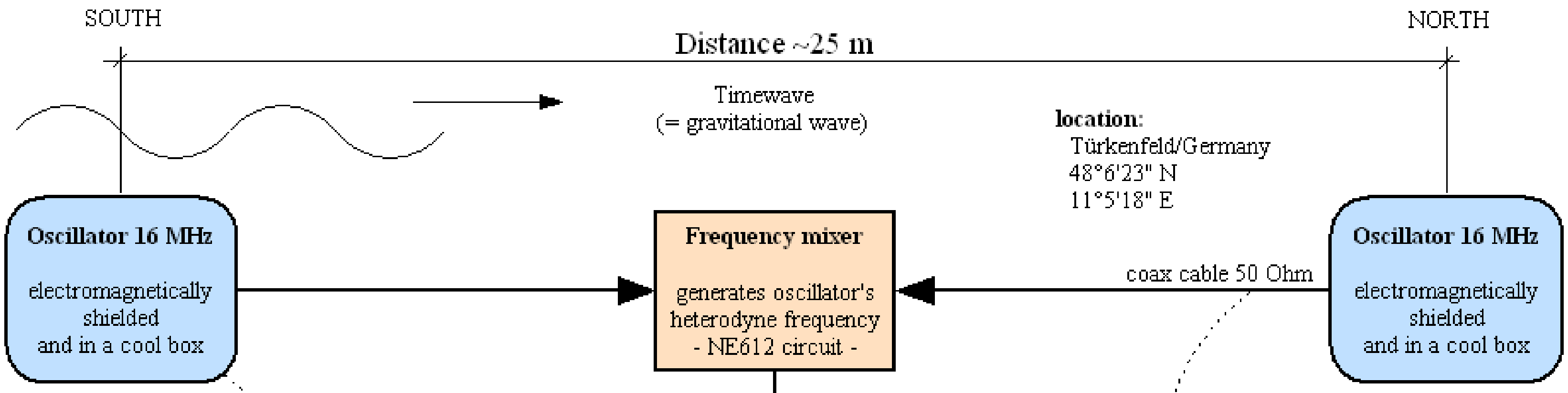
During discussions in the European Radio Astronomy Club (ERAC) about requirements for reference clocks in "Very Large Baseline Interferometry (VLBI)" systems it became obvious, that even the most accurate H2 maser clocks will fail if gravity changes in one of the locations of a VLBI system, e.g. due to movements in the Earth crust. In this case a change of gravity will be equivalent to a change of timeflow in that location which in turn will have impact on the reference clock's phase difference compared to other locations, independently how stable and how precise that reference clock might be.

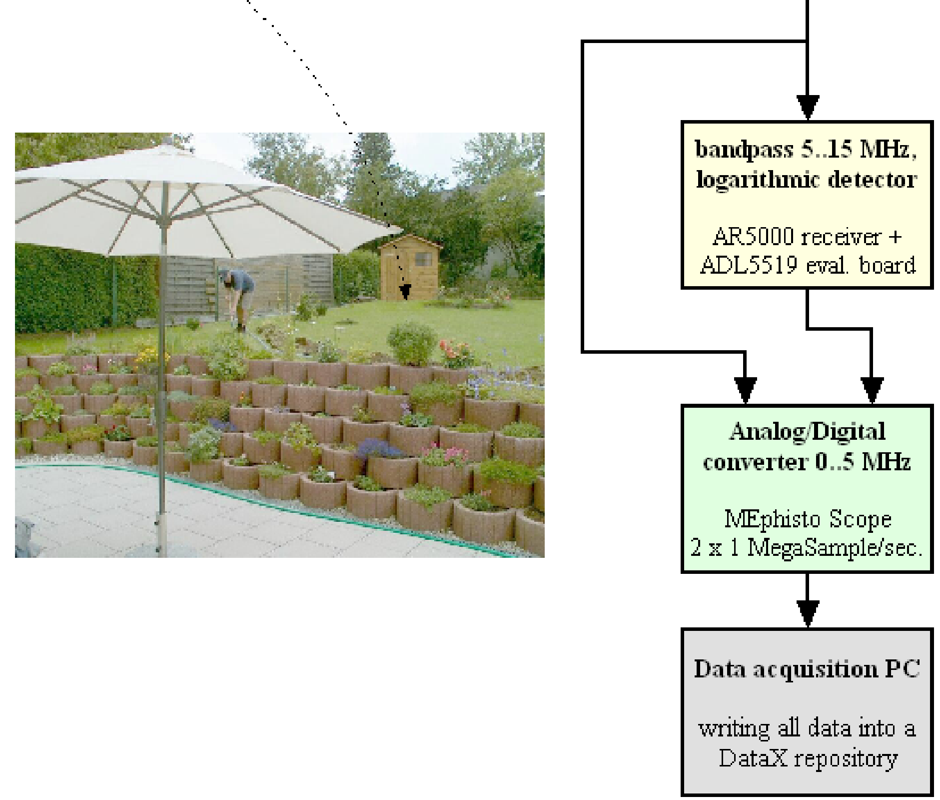
Those considerations provided to the idea of turning the things around and to measure gravity changes respectively timeflow changes by simply comparing the phases of distant oscillators.

System design

The measurement system mainly consists of two oscillators that are located in a distance and which phases are compared against each other in order to generate a heterodyne frequency. That signal is the subject of investigation. A first system has been started in continuous measurement mode end of July 2007. After introducing some improvements from insights of first measurement results the system is running stable since begin of October 2007. Overview charts of the captured measurement data are published on an almost daily basis in the Internet (http://wegalink.eu/research). The complete set of data is stored for various analysis approaches and can be obtained on DVD by everyone who is interested in this kind of research (one DVD per month, ~4.5 Gbytes). A possible chart will look as follows:







Supposed operating mode:

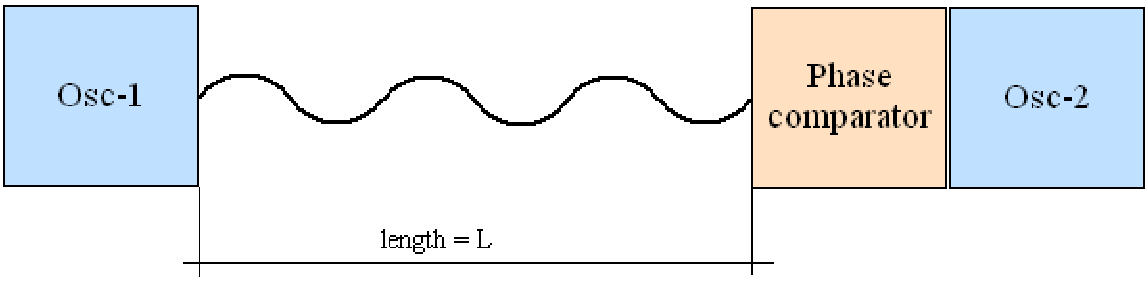
An assumed gravitational wave (what is the same as a **timewave** based on General Relativity) will make the phase velocity oscillating of the left oscillator compared to the phase of the oscillator on the right side until the timewave reaches the second oscillator.

A frequency mixer compares both oscillator's phase velocities and generates a heterodyne frequency. That output signal is the subject of investigation.

One channel of an ADC receives the DC signal of the mixer's output whereas a second channel evaluates the signal level in the shortwave range from about 5 to 15 MHz.

Explanation trial

The following description is my individual trial to explain the signals that could be expected on the system's output. This explanation may be incomplete or even completely wrong due to my limited theoretical knowledge. More profound explanations are welcome at any time and they can be sent to ERAC's mailing list: mailto:discussion@eracnet.org.



In my view there is a temporary unbalanced situation in a RF cable that connects Osc-1 in the above image with the phase comparator in the moment when gravity does change by a tiny increment. In this moment the time frame of the whole system will also change by a tiny increment in timeflow which in turn changes the wavelength in this local system. When the wavelength changes the electrical length of the cable will also change (different number of cycles inside L). The unbalanced situation will continue until the oscillations from before the gravity change will have left the cable. Since this takes place already in the new timeframe, the phase velocity of those "stored" Osc-1 cycles will be different and those differences can be detected by comparing Osc-1 phase against Osc-2 phase. That's all from my point of view what happens in the system when it is hit by a gravity change.

Overview about measurement data acquisition

The measurement is done by a "Pulse Data Recorder" that was designed especially for this purpose. In the following its main characteristics and working principles will be described.

Amount of data

The pulse data recorder has been designed for generating typically less than 100 MByte measurement data a day, independently from the sampling frequency and from the total number of values received from the analog/digital converter (ADC). This is achieved by pre-processing a block of sample data into a four-component value which stores the minimal and maximal values inside a sample block as well as the total value and a travel value.

For storage efficiency, the four components of a measurement value are stored as integers. In order to avoid loss of accuracy, the total value summarizes all values that belong to a sample block. Taking the known number of samples inside a sample block into account, the average can be calculated whenever it is needed with any desired accuracy.

The travel signal

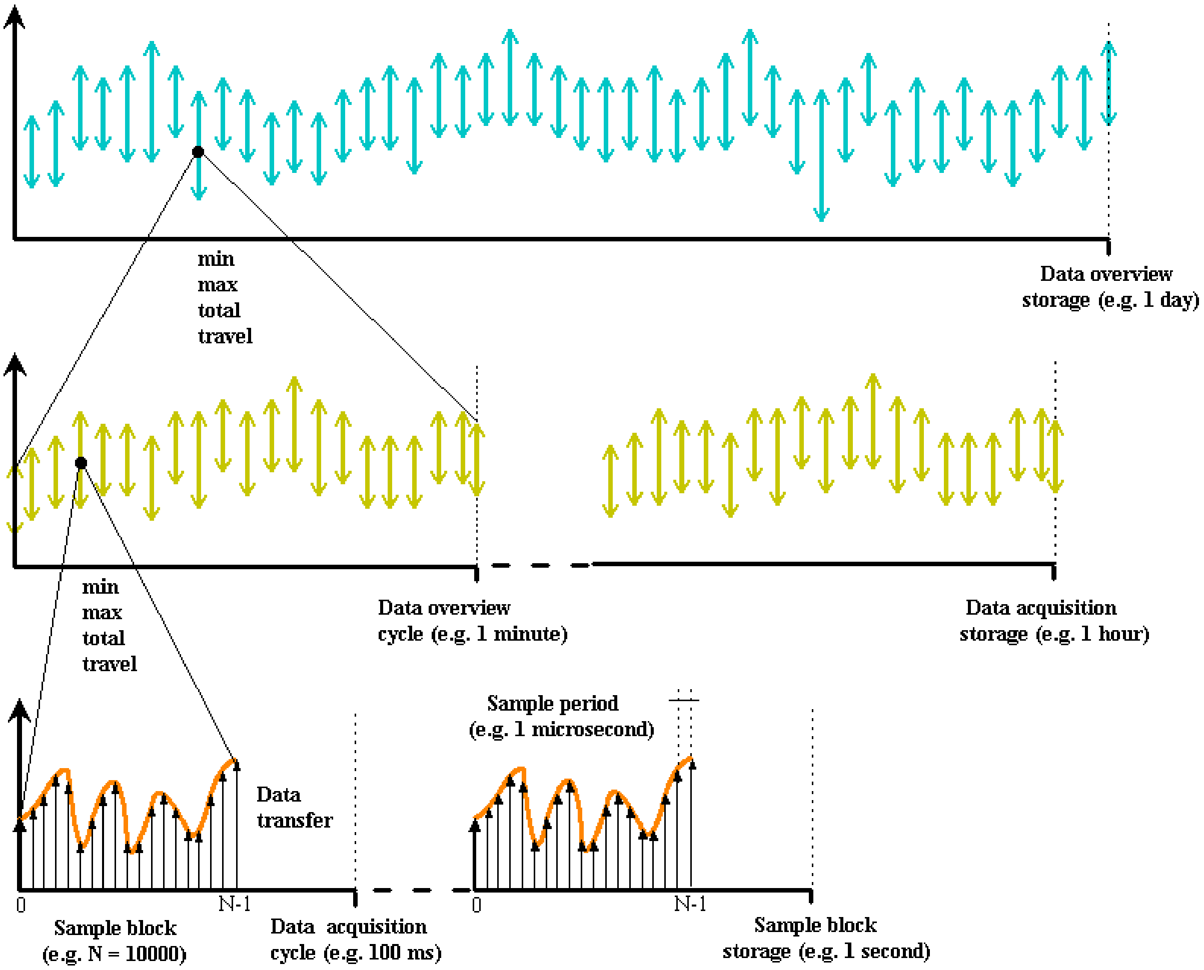
Similar to the total value, the travel value summarizes the differences between adjacent measurement values inside a sample block, also taking the difference between the last value of a sample block and the first value of the next sample block into account. This value is useful as an indicator of the dynamics inside a sample block. Whenever an additional signal appears inside the noise signal of a sample block the travel value will get higher. This is true even if the signal is below the noise level or if the signal itself is noise or changes the noise characteristics. Trigger can conveniently be derived from that travel signal for limiting the amount of data to the really interesting events.

System characteristics for a "MEphisto Scope" device

For example, a "MEphisto Scope" sampling device generates a total amount of about 35 Gigabytes data a day. After pre-processing that data stream by the Pulse Data Recorder "Wow" the amount of data is reduced to about 75 Megabytes a day which is about 0,2% of the original amount of data. Nevertheless the recorded data contains the run of the signal with 10 values per second consisting of the minimal, maximal, total and travel value inside each sample block. Additionally, a full sample block is available at the beginning of each minute and further for each unusual event in the data stream which exposes highs or lows in the monitored signal and/or in the derived travel signal whenever those signals exceeded a given threshold.

Data acquisition overview

The overall data acquisition process runs according to the following layout:



Data acquisition process

A sample block of N measurement values is acquired by the sampling device at a certain sampling frequency. In a next step all data is transferred from the buffer inside the sampling device to the RAM of a PC where the Pulse Data Recorder program runs. Ideally the data transfer should take place in parallel to the sample process which would allow to work with a continuous data stream where all samples are equally spaced. However, not all sampling devices allow for this highly desired procedure but transfer data to the PC when a sample block has finished. A next sample block can start but when the transfer has finished.

As it is shown on the chart a sample block is pre-processed into the four components: minimal, maximal, total and travel value which become one measurement value in the data acquisition storage. Subsequently, all those values inside a data overview cycle are further processed into a single four-component value in the data overview storage.

Data storage

The data files generated at the described three levels: sample block, data acquisition and data overview are stored in a DataX repository (see a detailed specification document at http://wegalink.eu/development/datax/index.htm). The filenames in a DataX repository are generated based on timestamps and the files themselves are put into a hierarchical folder structure which names are as well derived from timestamps. In addition to the ability of an automated processing of this pre-defined folder structure a DataX repository is also very convenient for managing the over and over increasing amount of stored data with common tools that operate on file systems.

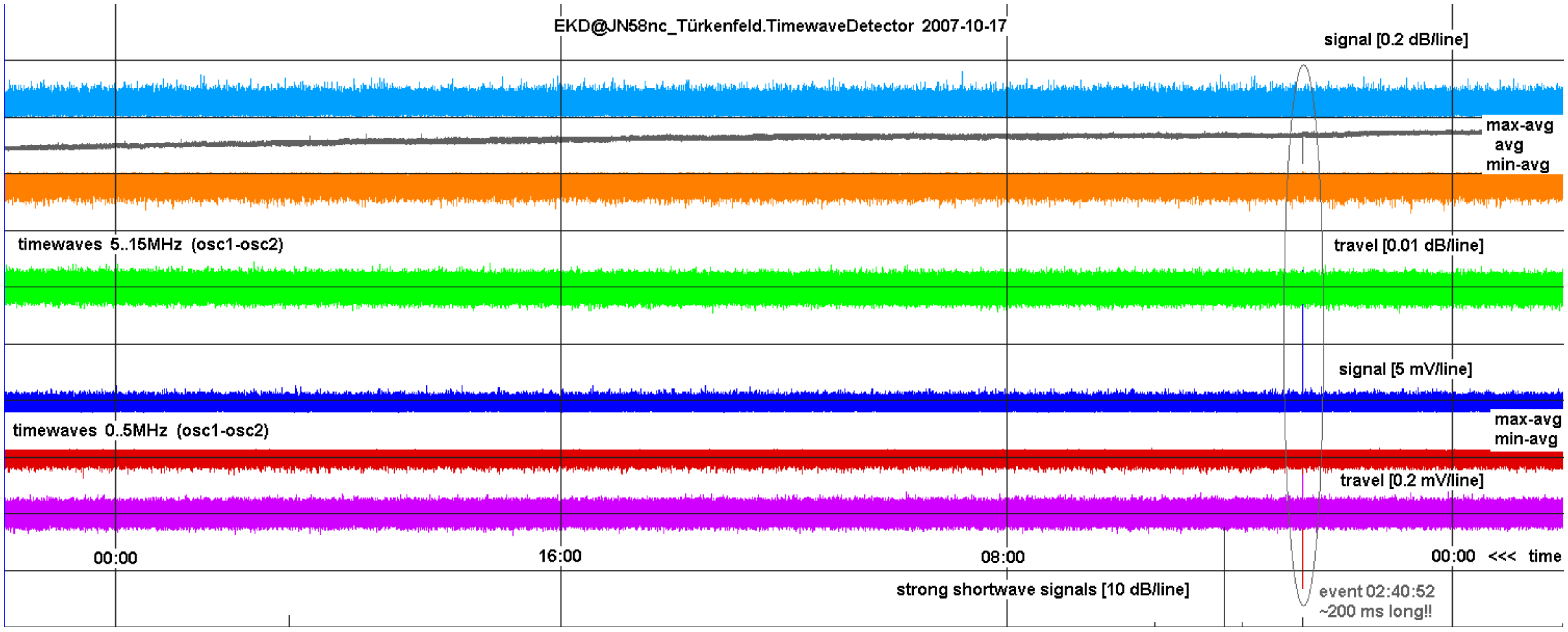
Characteristics and application

The advantage of the described two-step pre-processing procedure is - besides the already mentioned data reduction - a very fast access to an overview of all measurement data from a period of interest. Once an unusual high or low value of one of the four components has been detected the data can be further investigated by simply stepping down to the data in the acquisition storage and further to a sample block which finally will reveal the run of the signal at highest resolution. This raw data may be processed further into a spectrum view in order to see the one or multiple frequencies which possibly caused the deviation in the overview values. In addition, with a somewhat longer calculation process the scheduled sample blocks which are available for example each minute can be processed into a waterfall diagram. This kind of data representation is useful for detecting extremely weak but long lasting signals at a fix or slowly varying frequency.

Interferometry setup

The highest demand for amount of data as well as for sampling accuracy exists for interferometry setups where the signals of two or more antenna sites are combined into a single result data set. Usually sampling will take place continuously without break for a scheduled monitoring period, e.g. when the signals from a celestial object are visible to all receiving stations. During this scheduled monitoring period all data will be written to disk at high speed. The combined processing of signals, however, takes place after the monitoring period in a post-processing step where data will be exchanged between receiving stations at a speed which is usually limited by network (Internet) connectivity.

The Pulse Data Recorder "Wow" will work identically to the previously described procedure except that during a scheduled interferometry session in addition to previously described data a complete storage of all sample blocks will be done. This way the data analysis process during post-processing can benefit from all the before mentioned advantages and having nevertheless the complete set of data available for combining them into a compound result, e.g. fringes generated by earth rotation from a celestial object or multi-dimensional presentations of a celestial object in case of advanced research projects.



Negentropy event on October, 17th at 02:40:52 UTC

The chart on top shows one of the unusual signals that were recorded in the first months of the system's continuous run. In the detailed view of this event on the chart in the beginning it becomes visible that the recorded noise dropped by more than 1 dB for a relatively long time period of more than 30 milliseconds. Given that no system failure took place this would be an uncompared "negative entropy" event with a temperature equivalent of about 36 degree. This means the noise dropped as if the system's temperature was lowered by about 36 degree for more than 30 milliseconds. How could this happen?

Future plans

Feedback that I received from Peter Wrigth, ERAC's president, confirmed that investigations go into a very interesting direction. For further improvements the suggestion was to use only one oscillator, next a splitter and then as much (possibly folded forth and back) coax cable as possible in order to increase the system's sensitivity for gravitational waves. A commercial phase comparator will be put in the place where currently a NE612 circuit mixes the frequencies. The most advance in sensitivity, however can be expected from using a suggested oscillator in the Gigahertz range.