



## Beat-to-Beat Blood Pressure Monitor

**This invention is applicable to all segments of the blood pressure monitoring market, including ambulatory, home-based, and high-acuity monitoring.**

*Lyndon B. Johnson Space Center, Houston, Texas*

This device provides non-invasive beat-to-beat blood pressure measurements and can be worn over the upper arm for prolonged durations. Phase and waveform analyses are performed on filtered proximal and distal photoplethysmographic (PPG) waveforms obtained from the brachial artery. The phase analysis is used primarily for the computation of the mean arterial pressure, while the waveform analysis is used primarily to obtain the pulse pressure. Real-time compliance estimate is used to refine both the mean arterial and pulse pressures to provide the beat-to-beat blood pressure measurement.

This wearable physiological monitor can be used to continuously observe the beat-to-beat blood pressure (B3P). It can be used to monitor the effect of prolonged exposures to reduced gravitational environments and the effectiveness of various countermeasures.

A number of researchers have used pulse wave velocity (PWV) of blood in the arteries to infer the beat-to-beat blood pressure. There has been documentation of relative success, but a device that is able to provide the required accuracy and repeatability has not yet been developed. It has been demonstrated that an accurate and repeatable blood pressure measurement can be obtained by measuring the phase change (e.g., phase velocity), amplitude change, and distortion of the PPG waveforms along the brachial artery. The approach is based on comparing the full PPG

waveform between two points along the artery rather than measuring the time-of-flight. Minimizing the measurement separation and confining the measurement area to a single, well-defined artery allows the waveform to retain the general shape between the two measurement points. This allows signal processing of waveforms to determine the phase and amplitude changes.

Photoplethysmography, which measures changes in arterial blood volume, is commonly used to obtain heart rate and blood oxygen saturation. The digitized PPG signals are used as inputs into the beat-to-beat blood pressure measurement algorithm. The algorithm consists of the following main components:

- First harmonic isolation bandpass filters take the raw PPG signals and separate out the first harmonics.
- Three harmonic lowpass filters take the PPG signal and filter out all spectral components outside the first three harmonics. The first three harmonics are used for regeneration of the pulse pressure waveforms.
- Phase analysis engine takes the first harmonics of the PPG signals and computes the phase difference between them in real time using a cross-correlation-based algorithm. The phase difference is to the first order correlated to the MAP (mean arterial pressure).
- Compliance estimation engine takes information on the general shape of the waveforms and the phase delay to compute the local compliance of the

artery. The higher the arterial pressure, the higher the Young's modulus and thus the lower the compliance.

- MAP computation engine obtains the phase delay and compliance information and provides the mean arterial pressure.
- Waveform analysis engine takes the PPG signal containing the first three harmonics and provides the signal processing needed for compliance (elasticity) estimation and pulse pressure computation.
- Pulse pressure computation engine takes the filtered PPG signal and an estimate of the arterial compliance to regenerate the pulse waveform.
- B3P computation engine takes the MAP and the pulse pressure computations and combines them with a blood pressure model and calibration data to produce the final signal of interest — the beat-to-beat blood pressure.

*This work was done by Yong Jin Lee of Linea Research Corporation for Johnson Space Center. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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*Refer to MSC-24601-1, volume and number of this NASA Tech Briefs issue, and the page number.*

## Measurement Techniques for Clock Jitter

**New approach offers more advanced coded modulation techniques.**

*Lyndon B. Johnson Space Center, Houston, Texas*

NASA is in the process of modernizing its communications infrastructure to accompany the development of a Crew Exploration Vehicle (CEV) to replace the shuttle. With this effort comes the oppor-

tunity to infuse more advanced coded modulation techniques, including low-density parity-check (LDPC) codes that offer greater coding gains than the current capability. However, in order to take

full advantage of these codes, the ground segment receiver synchronization loops must be able to operate at a lower signal-to-noise ratio (SNR) than supported by equipment currently in use.

At low SNR, the receiver symbol synchronization loop will be increasingly sensitive to transmitter timing jitter. Excessive timing jitter can cause bit slips in the receiver synchronization loop, which will in turn cause frame losses and potentially lead to receiver and/or decoder loss-of-lock. Therefore, it is necessary to investigate what symbol timing jitter requirements on the satellite transmitter are needed to support the next generation of NASA coded modulation techniques.

Measurements of ground segment receiver sensitivity to transmitter bit jitter were conducted using a satellite transponder and two different commercial staggered quadrature phase-shift keying (SQPSK) receivers. The symbol synchronizer loop transfer functions were characterized for each receiver. Symbol timing jitter was introduced at

the transmitter. Effects of sinusoidal (tone) jitter on symbol error rate (SER) degradation and symbol slip probability were measured. These measurements were used to define regions of sensitivity to phase, frequency, and cycle-to-cycle jitter characterizations. An assortment of other band-limited jitter waveforms was then applied within each region to identify peak or root-mean-square measures as a basis for comparability.

Receiver clock recovery loops that operate in low SNR ratio environments require that transmit clock jitter be constrained by several measures on different dimensions and operating regions. In this work, effects of transmit phase jitter (PhJ), frequency jitter (FJ), and cycle-to-cycle jitter (CCJ) were studied for sinusoidal and multi-tone jitter profiles on receiver performance. It was demonstrated that the receiver must have a loop band-

width tight enough to avoid cycle slips, but loose enough to track some movement in the data signal. Movement that a tight loop cannot track is usually manifested first as intersymbol interference (ISI) (SER degradation) and then ultimately as cycle slipping in the receiver.

Results from the tests indicate that the receiver symbol synchronization loop is more sensitive to certain types of symbol jitter and jitter frequencies, depending on the selection of the loop filter and damping ratio. A framework is provided to properly compose a transmit jitter mask depending on receiver design parameters such as damping ratio in order to limit receiver performance degradation at low SNR regions.

*This work was done by Chatwin Lansdowne and Adam Schlesinger of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24810-1*

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## **Lightweight, Miniature Inertial Measurement System**

*Goddard Space Flight Center, Greenbelt, Maryland*

A miniature, lighter-weight, and highly accurate inertial navigation system (INS) is coupled with GPS receivers to provide stable and highly accurate positioning, attitude, and inertial measurements while being subjected to highly dynamic maneuvers. In contrast to conventional methods that use extensive, ground-based, real-time tracking and control units that are expensive, large, and require excessive amounts of power to operate, this method focuses on the development of an estimator that makes use of a low-cost, miniature accelerometer array fused with traditional measurement systems and GPS. Through the use of a posi-

tion tracking estimation algorithm, onboard accelerometers are numerically integrated and transformed using attitude information to obtain an estimate of position in the inertial frame. Position and velocity estimates are subject to drift due to accelerometer sensor bias and high vibration over time, and so require the integration with GPS information using a Kalman filter to provide highly accurate and reliable inertial tracking estimations.

The method implemented here uses the local gravitational field vector. Upon determining the location of the local gravitational field vector relative to two consecutive sensors, the orientation of

the device may then be estimated, and the attitude determined. Improved attitude estimates further enhance the inertial position estimates. The device can be powered either by batteries, or by the power source onboard its target platforms. A DB9 port provides the I/O to external systems, and the device is designed to be mounted in a waterproof case for all-weather conditions.

*This work was done by Liang Tang of Impact Technologies and Agamemnon Crassidis of the Rochester Institute of Technology for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16132-1*

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## **Optical Density Analysis of X-Rays Utilizing Calibration Tooling to Estimate Thickness of Parts**

**This method uses off-the-shelf data analysis software and a digitized x-ray for nondestructive testing.**

*John F. Kennedy Space Center, Florida*

This process is designed to estimate the thickness change of a material through data analysis of a digitized version of an x-ray (or a digital x-ray) containing the material (with the thickness in question) and various tooling. Using this process, it is possible to estimate a

material's thickness change in a region of the material or part that is thinner than the rest of the reference thickness. However, that same principle process can be used to determine the thickness change of material using a thinner region to determine thickening, or it can

be used to develop contour plots of an entire part.

Proper tooling must be used. An x-ray film with an S-shaped characteristic curve or a digital x-ray device with a product resulting in like characteristics is necessary. If a film exists with linear