Australian Government
Australian Transport Safety Bureau

Burst Timing Offset (BTO) Characteristics

MH370

23 December 2014

Background

The Australian Transport Safety Bureau (ATSB) is leading the search for missing Malaysia Airlines Flight 370 in the southern Indian Ocean.

The most promising clues to the final location of the aircraft are satellite communication (SATCOM) signals between MH370, the Indian Ocean Region Inmarsat satellite, and the Inmarsat ground station in Perth, WA. Work by an international team of specialists using the Burst Timing Offset (BTO) identified the seventh arc as the likely final location of MH370. Further work has been done using the Burst Frequency Offset (BFO) to identify the priority search area along the seventh arc.

The ATSB has been asked to provide further technical information on the BTO jitter or variation characteristics. The ATSB has been approached with questions regarding an observed 'jitter' characteristic in the BTO signal and its relationship in determining the location of the 7th arc. This factsheet details work done to clarify and determine the source of the 'jitter'. The presence of the jitter was taken into account during the original analysis and the location of the seventh arc and placement of the search area allow for any effect it might have on calculations.

Burst Timing Offset (BTO)

The Burst Timing Offset (BTO) as recorded on the Inmarsat Satellite Communications (SATCOM) log (released by Malaysia) is a measure of the time taken for a transmission round trip (ground station to satellite to aircraft and back) and allows a calculation of the distance between the satellite and the aircraft. Based on this measure, possible location rings were mapped on the surface of the earth. A validation determined that the tolerance of the rings was ± 10 km.

The 'jitter'

The SATCOM system is a communications system designed to meet the Inmarsat specifications. It was not designed to be used as a positioning system so the accuracy of the BTO measurements was not explicitly known at the time of the accident flight. The ATSB sourced advice from the MH370 SATCOM working group to provide the following information.

The jitter on the BTO is due to a number of components within the return path between the Ground Earth Station (GES) and the Airborne Earth Station (AES).

- The noise in the AES receiver when detecting the time of the P-channel unique word.
- The quantisation of the AES transceiver internal time reference.
- The noise in the GES receiver when measuring the time of arrival of the AES transmission.
- The quantisation of the BTO measurement.

Items 1 and 3 are similar processes. For item 1 the AES has the advantage of being able to track the P-channel unique word continuously and so it uses a much narrower bandwidth than the GES (which can only detect the unique word for a single reply). The dominant contribution is therefore from the GES measurement. An experiment was conducted to measure the effective contribution due to item 3.

Test 1. R1200, no noise, 1000 bursts
Mean BTO: 0.00 μs
Stdev BTO: 0.00 μs

The above indicates no systematic bias or significant data dependency.

Test 2. R1200, 39 dBHz noise, 1000 bursts
Mean BTO: -2.08 μs
Stdev BTO: 17.10 μs

Item 2 comes from the way in which the AES transmits its signals. The AES receives the unique word in the P-channel and tracks this continuously so that it can determine the correct time to transmit when necessary. The system uses a reference/sample clock at 42KHz for the IQ samples resulting in an effective reference time captured with a resolution of ~24μs. Since the clocks are not synchronised and the satellite and AES are moving, the precise time of the unique word will drift through the reference clock cycles such that the reference time error will resemble a sawtooth stepping up or down according to the direction of drift. Since there are very infrequent samples of this error, we observe an error of +/-12μs with a truncated non-Gaussian distribution.

Item 4 arises because of the 20μs resolution of the GES BTO measurement.

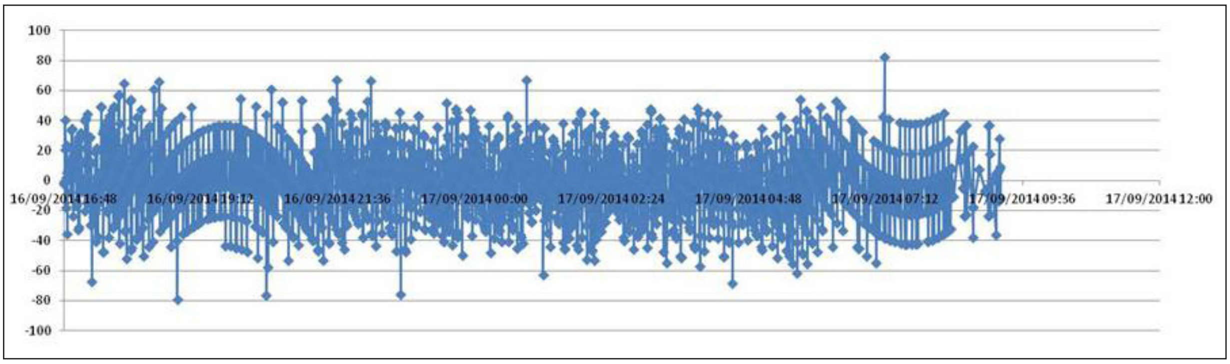
The MH370 SATCOM working group undertook a number of steps to validate the accuracy of the available BTO measurements during the initial stages of their work. In particular, the group obtained data from a large number of flights where both BTO and ACARS position data were available. The results indicated that the BTO measurements were accurate to better than 50μs or approximately 10km on the ground.

The group also conducted experiments with a static AES in order to characterise its behaviour under a variety of scenarios. In the following analysis, data was collected between 16/09/2014 14:46 and 17/09/2014 09:13 with a regular transmission from the AES.

The following analysis represents the 1200 baud R channel data. Data from the 1200 baud T channel was also analysed with identical results.

The BTO errors were calculated by subtracting the measured BTO from the calculated BTO of the path between the GES and AES. The location of the satellite was calculated from the Inmarsat ECEF data and interpolated for the exact measurement epoch of each measurement. Figure 1 below shows the measured BTO error for the period with zero representing the overall mean error (calibration) for the data set.

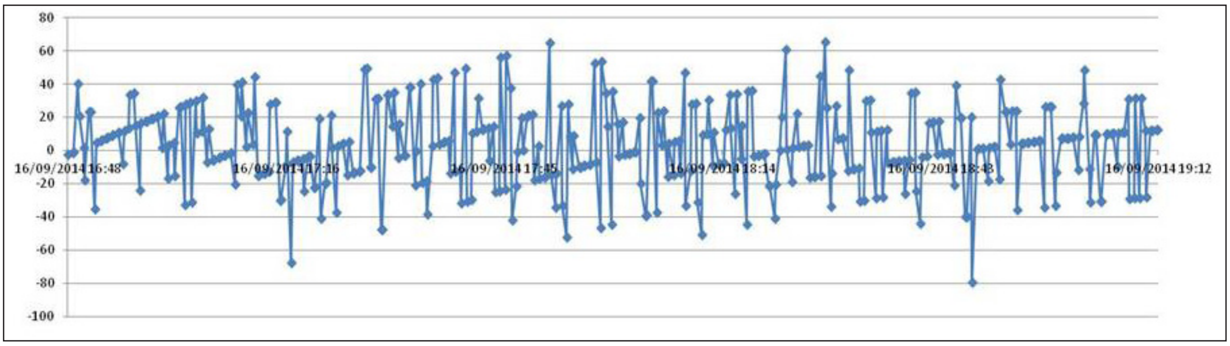
Figure 1: The measured BTO error for the period with zero representing the overall mean error (calibration) for the data set.



Source: Satellite Working Group

Figure 2 shows the first part in more detail.

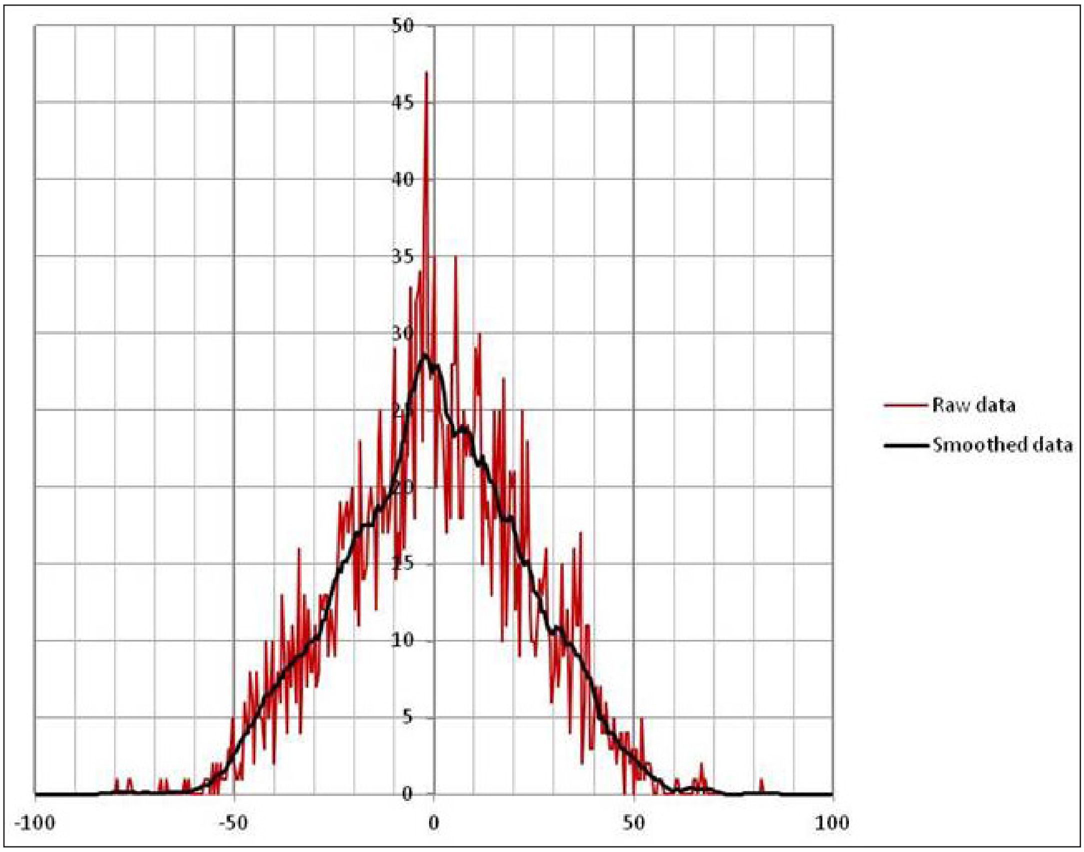
Figure 2: Detailed breakdown. Source: Satellite Working Group



The effect from the motion of the satellite and also the 20μs BTO measurement quantisation can be clearly seen. These steps and arcs are then subject to the receiver noise contribution in the AES and GES.

The following histogram (Figure 3) shows the distribution of the errors. The Y axis is Number and the X axis is Error in μs. The smoothed plot uses a simple rolling 19 bin filter to indicate the underlying shape which is clearly non-Gaussian as expected.

Figure 3: Histogram of BTO errors. Source: Satellite Working Group



The calculated statistics for this distribution are:

Statistics	μs
50%	15
95%	43
99%	53

These test results are in agreement with the understanding of the error components and the flight test experiments and supports the assertion of a 50μs effective accuracy. In the case of MH370, there are very few samples and so we cannot treat any particular measurement other than individually. Hence the assertion that a particular BTO has an accuracy of 50μs (at a 99% confidence level).

For reference, a 50μs error equates to a +/-7.5km error in satellite range. This equates to approximately +/-10km horizontal error on the Line of Position. This concurs with the reference flight measurement analysis.

More information

You can find more information on how the seventh arc and the priority search area were identified in the following publications:

The ATSB reports MH370 – *Definition of Underwater Search Areas* and *MH370 – Flight path analysis update.*