# Benchmark 4-target passive sonar scenario description for 1-D tracking

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# Benchmark 4-target passive sonar scenario description for 1-D tracking

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This document describes a simulated (but realistic) passive sonar scenario for benchmarking tracking algorithms based on one-dimensional (1-D) measurement data consisting of either frequency or bearing. The document accompanies the five data set ASCII files mentioned below and provides sufficient detail to generate data matching the data in the files or new data with different scenario parameters for acoustic contacts, ownship (submarine) and/or environment. The data and description presented here are released into the public domain to encourage researchers to use a common data set and share their results. Instructions for citing this data set are provided at the end of the document.

The passive sonar scenario used here has previously been reported in[1]:

[1] Brinkmann K., and J Hurka, "Narrowband Passive Sonar Tracking", Proc. Undersea Defence Technology (UDT) Europe 2010, Hamburg, June 2010.

[2] Brinkmann K., and J. Hurka. "Broadband Passive Sonar Tracking", in S. Fischer, et al. (editors), Informatik 2009 - Im Focus das Leben, vol. P-151 GIEdition - Lecture Notes in Informatics (LNI), 2009.

This scenario consists of 4 acoustic contacts (which by convention in target tracking we refer to as "targets") each emitting 4 different narrowband tones. The targets move with constant velocity and direction throughout the entire scenario duration of 4800 seconds. The resulting 1-D data sets contain multiple frequency lines of roughly constant frequency, some closely spaced, and bearing data with several crossings, both in a high false alarm density environment representative of real passive sonar data.

Target dynamical parameters are summarised in **Table 1** where $x_0$ is the initial position in 2-D Cartesian coordinates in kilometres (north = +y, east = +x), v is the speed and $\eta$ is the initial heading (north = 0, clockwise positive)

**Table 1:** Target dynamical parameters for the 4-target scenario.

| Target | $x_0$ (km) | $\eta$ (degrees) | v (m/s) |
|---|---|---|---|
| 1 | (0, 30.89) | 154.71 | 5.31 |
| 2 | (15.94, 13.30) | 240.42 | 6.35 |
| 3 | (-7.80, 13.30) | 90 | 11.29 |
| 4 | (-1.70, -10.0) | 329.75 | 6.32 |

Each target emits acoustic tonals at a source level of 160 dB. The frequencies for each target are summarised in **Table 2** where $f_n$ is the frequency of the $n^{th}$ tone. Each target also produces 10 dB of white broadband noise in the band from 0 to 1200 Hz.

**Table 2:** Emission parameters for the 4-target scenario.

| Target | $f_1$ (Hz) | $f_2$ (Hz) | $f_3$ (Hz) | $f_4$ (Hz) |
|---|---|---|---|---|
| 1 | 400 | 450 | 520 | 570 |
| 2 | 580 | 620 | 690 | 715 |
| 3 | 430 | 525 | 685 | 1000 |
| 4 | 867 | 879 | 900 | 917 |

[1] The simulation parameters reported here may differ slightly from the scenario in the references. Also note that, for simplicity, multipath interference is not modelled in this simulation whereas it was modelled in [1] and [2].

The ownship starts at the origin and performs a series of typical localisation manoeuvres. These manoeuvres are outlined in **Table 3** where η is the heading to attain (north = 0, clockwise positive), R is the turn radius and t is the time at which this manoeuvre occurs. The ownship has a constant speed of 3 m/s for the entire simulation, including during manoeuvres. The turn radius R is shown with both positive and negative values. A positive turn radius corresponds to a clockwise turn and a negative turn radius corresponds to an anti-clockwise turn.

**Table 3:** Ownship dynamic manoeuvres for the 4-target scenario.

| Manoeuvre | t (hh:mm:ss) | η (degrees) | R (m) |
|---|---|---|---|
| 0 | 00:00:00 | 70 | 0 |
| 1 | 00:10:00 | 295.54 | –101 |
| 2 | 00:21:27 | 110 | 98 |
| 3 | 00:33:20 | 355.55 | –90 |
| 4 | 00:44:33 | 170 | 97.5 |
| 5 | 01:01:23 | 10 | –85 |
| 6 | 01:18:13 | 180 | 120 |

**Figure 1** shows the true target and ownship trajectories for this simulation. The red circle on the graph indicates the end point of a target trajectory.

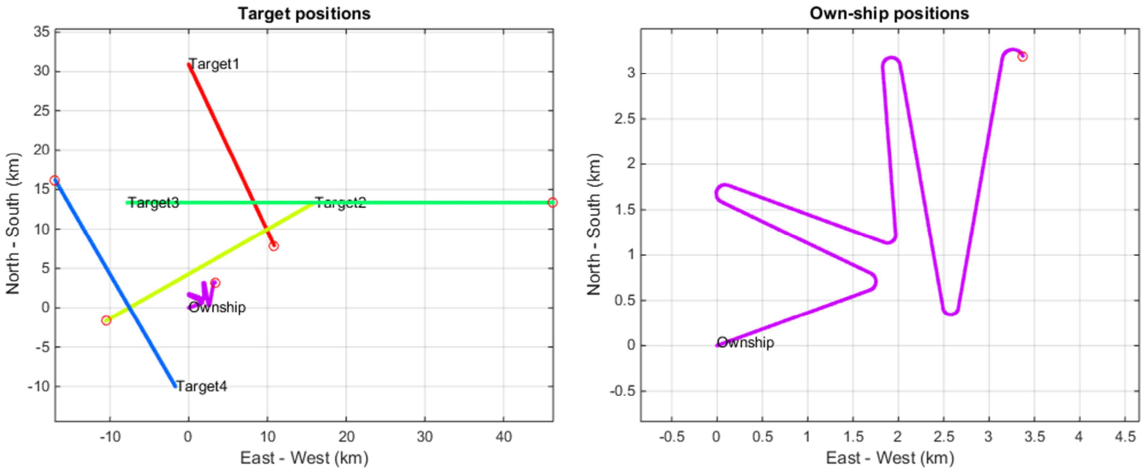


**Figure 1 :** Target and ownship trajectories for 4-target scenario.

**Figure 2** shows the noise-free true bearing and frequency data with detection probability $P_D$ = 1 and no false alarms. Note that the measurement data are subject to a detection process and also contain false alarms.

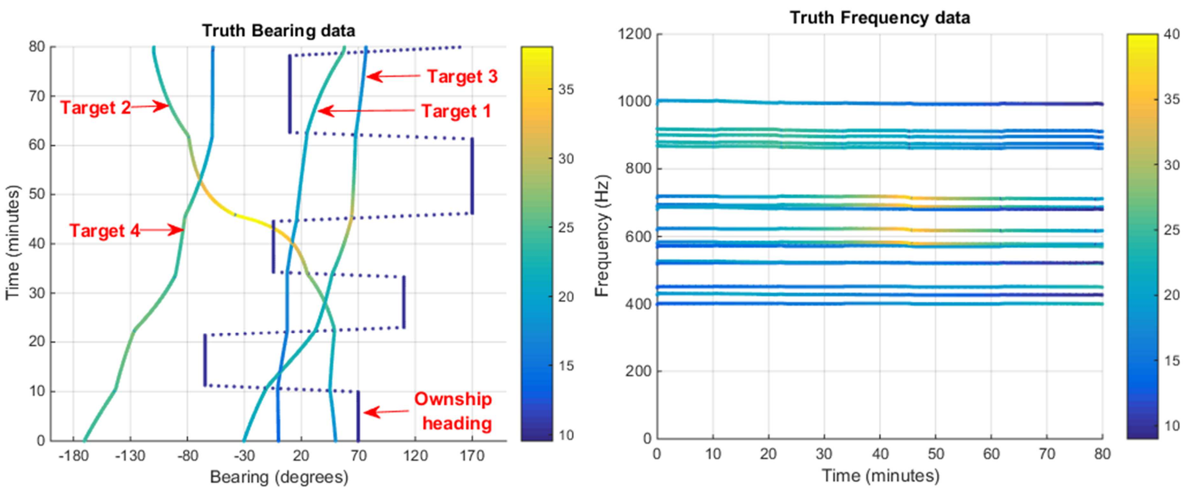


**Figure 2 :** True bearing and frequency data and ownship heading for 4-target scenario.

The Doppler shifted frequency ($f_d$) and a frequency-independent transmission loss TL (dB re 1µPa at 1m) is also applied to the dB source level according to the formulas:

$$f_d = \left( \frac{c - \boldsymbol{v}_{ownship} \cdot \hat{\boldsymbol{r}}_{TO}}{c - \boldsymbol{v}_{target} \cdot \hat{\boldsymbol{r}}_{TO}} \right) f$$

$$\hat{\boldsymbol{r}}_{TO} = \frac{\boldsymbol{r}_T - \boldsymbol{r}_O}{\|\boldsymbol{r}_T - \boldsymbol{r}_O\|} = \frac{\boldsymbol{r}_T - \boldsymbol{r}_O}{r}$$

$$TL(r) = 20 \times \log 10(r)$$

where $\boldsymbol{v}$ is the velocity vector, $\boldsymbol{r}$ is the position vector, $f$ is the source frequency, $r$ is the range from the source to the receiver, $c$ is the speed of sound in water (assumed to be 1500 $ms^{-1}$). Bold type denotes vector quantities, all of which are in SI units. Subscripts O and T denote ownship and target respectively.

The simulated array assumes a 5 degree blind spot to the aft of the ownship, as might occur with a sonar mounted at the front of the ownship. The blind spot is modelled by the array directivity gain shown in **Figure 3**.

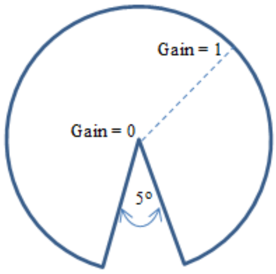


**Figure 3 :** Blind spot model for 4-target scenario.

Ambient noise is generated at a level equivalent to sea state 2 based on the Knudsen curves.

$$Level = 50 + 7.5 \times \sqrt{Windspeed(seaState)} + 20 \times log_{10} \frac{f}{1000} - 40 \times log_{10} \left( \frac{f}{1000} + 0.4 \right)$$

where f is the frequency in Hz and wind speed as a function of sea state is defined in **Table 4**.

**Table 4:** Sea state characteristics

| Sea State | Wave height (m) | Wind speed (m/s) | Characteristics |
|---|---|---|---|
| 0 | 0 | 0.7717 | Calm (glassy) |
| 1 | 0 to 0.1 | 2.5722 | Calm (rippled) |
| 2 | 0.1 to 0.5 | 4.3728 | Smooth (wavelets) |
| 3 | 0.5 to 1.25 | 6.945 | Slight |
| 4 | 1.25 to 2.5 | 9.7744 | Moderate |
| 5 | 2.5 to 4 | 12.6039 | Rough |
| 6 | 4 to 6 | 19.2917 | Very rough |
| 7 | 6 to 9 | 26.4939 | High |
| 8 | 9 to 14 | 30.6094 | Very high |
| 9 | Over 14 | 32.9244 | Phenomenal |

The mean power in the ambient noise is used to calculate the SNR of the received signal at the sonar array. Amplitude $s$ is modelled as Rayleigh distributed for both targets and false alarms (clutter) with clutter amplitude independent of range and generated via

$$s_{FA} = T^2 - 2\log(1-u), \quad u \sim U[0,1]$$

where T is the detection threshold (taken as 3) and $u$ is a uniformly distributed random number.

Target amplitude is generated via

$$s_0 = T^2 - 2(1 + A)\log(1 - u), \;\; u \sim U[0,1]$$

where A is the (non-dB) SNR of the received signal. Measurement noise is assumed to be Gaussian (with no truncation) with zero mean and standard deviation 0.2 Hz for the frequency and 0.3 degrees for the bearing data sets respectively. False alarms are uniformly distributed in frequency (f ~ U[0,1200]) and bearing and Poisson distributed in number with average 80 per slice. The sampling time is taken as 4 seconds. Finite sensor resolution is also simulated so that measurements within 0.5 Hz and 0.25 degrees of each other are combined by averaging the two samples.

Data sets with these parameters are provided in 5 text files:

1. BearingEvents.txt
2. FrequencyEvents.txt
3. TruthBearingEvents.txt
4. TruthFrequencyEvents.txt
5. TargetPositions.txt

Files 1 through 4 are expressed as a 3-column vector with time in seconds in column 1, frequency in Hz or bearing in degrees in column 2, and SNR in dB in column 3. A line of 3 zeros is placed at the start of each new slice of data including the first slice. Files 1 and 2 contain the list of detections, including false alarms and missed detections over the simulation period. Files 3 and 4 contain the noise-free target truth without false alarms for bearing and frequency respectively.

File 5 includes the noise free target positions expressed as a 16-column vector with time in seconds in column 1. Columns 2, 3 and 4 represent the x, y, z positions of target 1, columns 5,6 and 7 represent the x, y, z positions of target 2 and so on. The final three columns represent the ownship positions. Note that the depth z is zero for the simulation described here.

The raw frequency and bearing data are shown graphically in **Figure 4** and **Figure 5**.

This data set should be referenced using the following citation:

Tyson, K., P. and Pulford, G., W., “Benchmark 4-target passive sonar scenario description for 1-D tracking”, published on ResearchGate, February 2015.

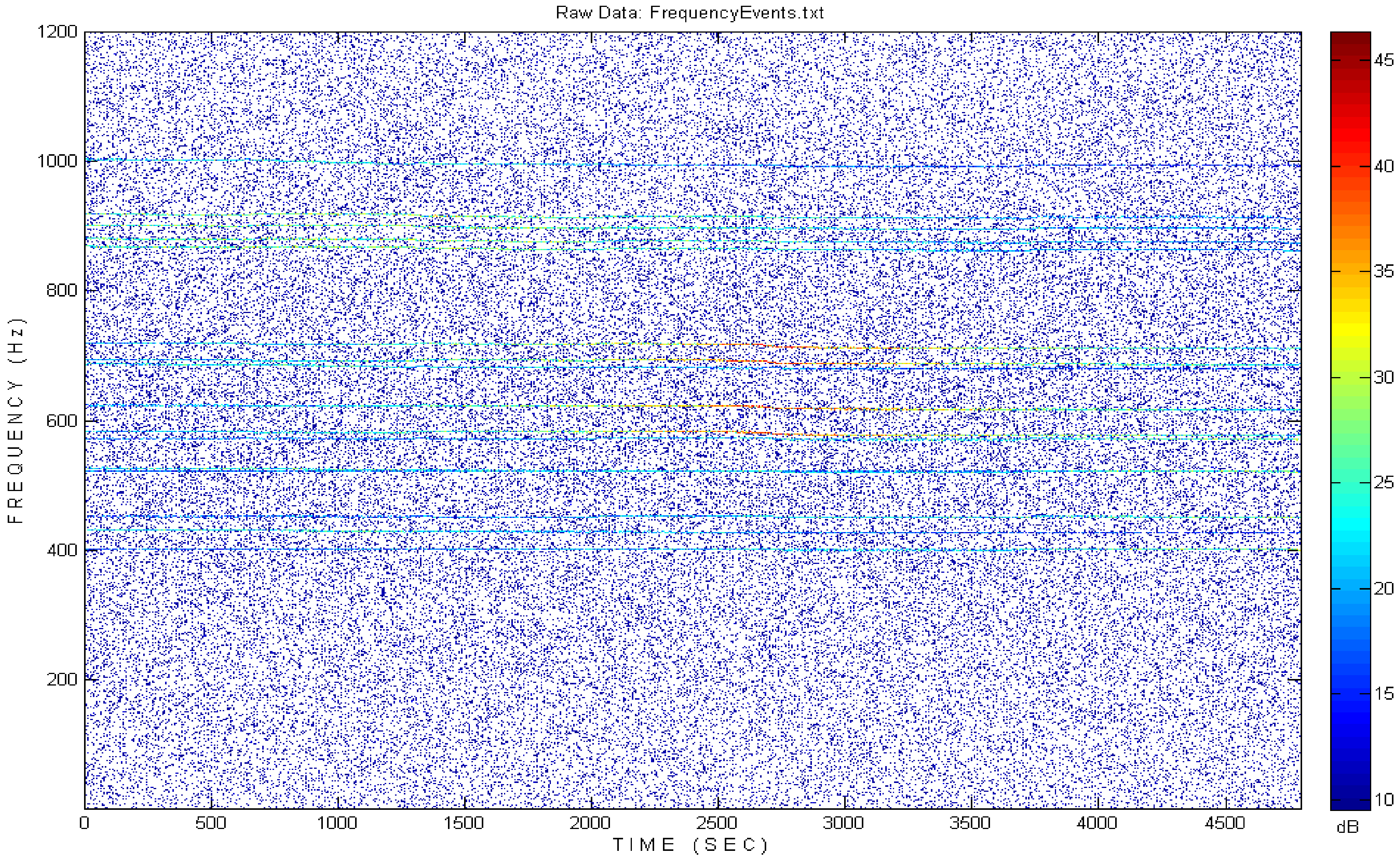


**Figure 4 :** Simulated frequency-time data.

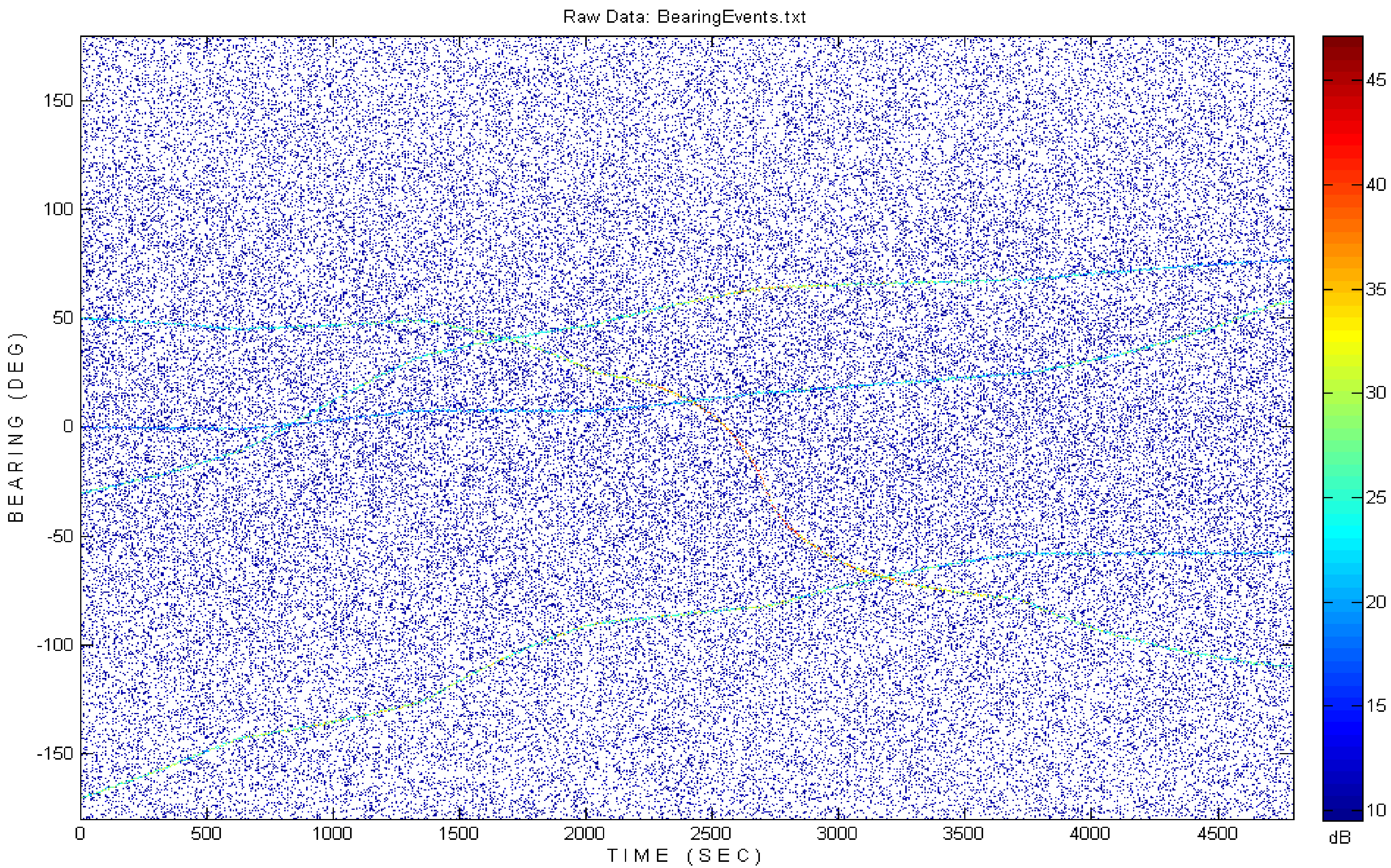


**Figure 5 :** Simulated bearing-time data.