Study

on Detection of Audio Anomalies on CVR Recordings
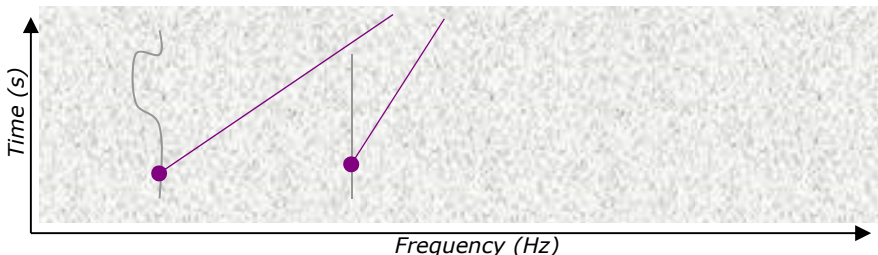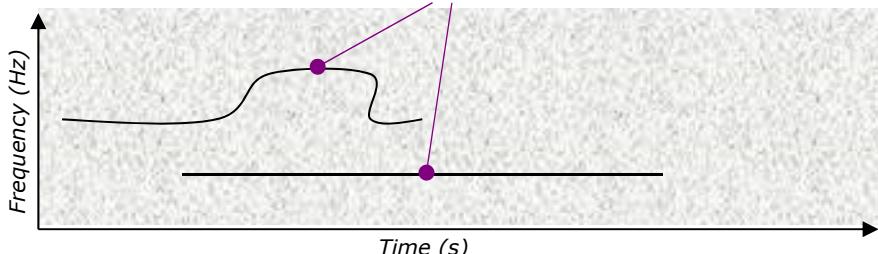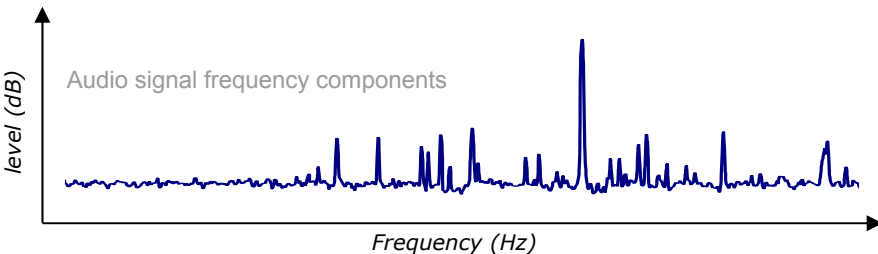
BEA

Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

Ministère de l'Ecologie, du Développement durable et de l'Energie

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Glossary

CAM	*Cockpit Area Microphone*
Frequency	*Number of repetitions of a phenomenon within a particular period*
Fundamental	*Lowest frequency of a periodic waveform*
Lofargram (Lofar)	*Spectrum view (LOFAR) : graph with frequency on X-axis and time on Y-axis* Audio signal frequency components *Time (s)* *Frequency (Hz)*
H (n)	*Harmonic rank n*
Harmonic family	*The whole of frequencies multiple of the fundamental*
Sonagram (Sonar)	*Spectrum view (SONAR): graph with time on X-axis and frequency on Y-axis* Audio signal frequency components *Frequency (Hz)* *Time (s)*
SPL	*Source Power Level (sound analysis view): graph with frequency on X-axis and level of energy on Y-axis* Audio signal frequency components *level (dB)* *Frequency (Hz)*

1 - INTRODUCTION

In recent years, numerous investigations conducted by various accident investigation authorities (BEA, NTSB, AAIB, TSB, etc.) were slowed down due to the absence or poor quality of cockpit voice recorder (CVR) data.

This equipment, which is not used daily by aircraft operators, is dedicated to safety investigations with the sole objective of getting a better understanding of the event for improvements in flight safety. The critical importance of the CVR is evident to those involved in the world of aviation only after an accident. It then becomes unacceptable to the aeronautical community to find unusable recordings on the CVR.

Since the early 90s, the BEA has been involved in the evaluation of the quality of CVR channel audio recordings on behalf of French aircraft manufacturers. These assessments associated with audio analysis in safety investigations have significantly increased the BEA's experience and improved its database of potential anomalies.

This document should enable stakeholders in the aviation industry to check, at the very least, if regularly encountered anomalies are present or not on the CVR recordings from their aircraft.

2 - PURPOSE OF THE DOCUMENT

This document was written to provide a general methodology for checking CVR recordings (Chapter 3) and list the main anomalies encountered by the BEA during work on CVR recordings, whether in the context of safety investigations or evaluations of audio quality for the benefit of manufacturers and operators (Chapter 4). This document should not be considered exhaustive.

European Regulation 965/ 201 (PART CAT.GEN.MPA.195 CAT) makes it mandatory for operators to conduct an annual inspection of CVR recordings. This inspection mainly consists of checking that the recordings are audible and intelligible. The methodology is described in chapters 3 and 4.1.

When installing or modifying a CVR system or adding a modification to the cockpit that can affect this system, a thorough check of recordings is necessary. The information provided in 4.1 and the following chapters describes the main anomalies that have been encountered for which the absence should be verify.

Regulatory references:

- ☐ Commission Regulation (EU) No 965/2012 - 5 October 2012 – Annex IV – Part-CAT;
- ☐ Annex 6 to the International Convention on Civil Aviation (ICAO) Operation of Aircraft;
- ☐ EASA CM No.: EASA CM - AS – 001 Issue: 01 of 12 June 2012;
- ☐ EASA Safety Information Bulletin n° 2009-28R1 *"Flight Data Recorder and Cockpit Voice Recorder Dormant Failures"*. http://ad.easa.europa.eu/ad/2009-28R1

Technical references:

- ☐ ED-55 *"Minimum Operational Performance Specification for Flight Data Recorder Systems"*;
- ☐ ED-56A *"Minimum Operational Performance Specification for Cockpit Voice Recorder Systems"*;
- ☐ ED-112 *"Minimum Operational performance Specification for Crash Protected Airborne Recorder Systems"* – see. appendices I-C and II-B Maintenance Practices.

Major accidents in which the CVR recording could not be recovered due to a failure of the CVR system:

- ☐ Auxiliary Power Unit Battery Fire Japan Airlines Boeing 787-8, JA829J Boston, Massachusetts January 7, 2013[1];

- ☐ Interim report on the accident on June 29, 2009 at sea off the coast of Moroni (Comoros) to the Airbus A310-324 registered 7O-ADJ operated by Yemenia Airways[2];

- ☐ Investigation Report on the Accident to Ethiopian 409 – Boeing 737-800 Registration ET-ANB at Beirut – Lebanon on 25th January 2010[3];

- ☐ Press release on 2 April 2014 on the accident to the McDonnell Douglas MD-83, registered EC-LTV, on 24 July 2014 in the region of Gossi (Mali)[4].

3 - METHODOLOGY FOR EVALUATION OF CVR RECORDINGS

During an audio evaluation, it is necessary to work on the data of each track recorded on the CVR (generally between 3 and 6 tracks)

For example, the following audio files are usually recovered:

- ☐ A file with the recording of radio communications and left side pilot microphones signal;
- ☐ A file with the recording of radio communications and right side pilot microphones signal;
- ☐ A file with the recording of radio communications, third man (jump seat) microphone signal, conversations with the cabin crew and the FSK signal when recorded (see §4.8);
- ☐ A file with the recording of a mix of the first 3 tracks;
- ☐ A file with the recording of the signal from the Cockpit Area Microphone (CAM).

[1]http://www.ntsb.gov/investigations/AccidentReports/Reports/AIR1401.pdf

[2] http://www.bea.aero/docspa/2009/7o-j090629e1/pdf/7o-j090629e1.pdf

[3]http://www.bea.aero/docspa/2010/et-b100125.en/pdf/et-b100125.en.pdf

[4]http://www.bea.aero/en/enquetes/flight.ah.5017/flight.ah.5017.php

The number of recovered audio files and their duration varies depending on the type of aircraft[5].

The download of the CVR must generate, at least, the number of audio files expected for the duration defined by the recorder specification (currently more than 30 minutes or 2 hours).

Some audio analysis software, fairly intuitive, is available (eg Audacity, Samplitude, Soundforge, etc). Its use makes evaluation easier and more comfortable. This software makes it possible to navigate through the audio file, to view the waveform and thus to quickly identify some anomalies (eg absence of signals).
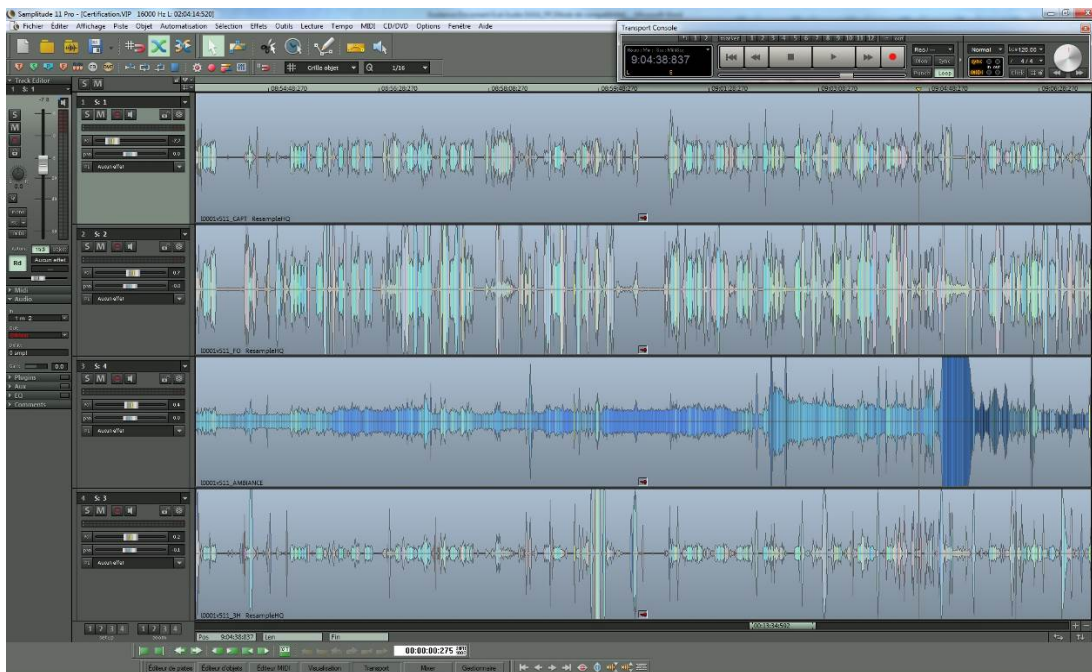

Figure 1 - samplitude audio analysis software interface

The first elements in an audio evaluation are as follows:

☐ 1 - Once the audio files are opened with the software, ensure that they contain audio data with no audio blanks (see § 4.1). The possibility of viewing the waveform with audio analysis software (see figure 1) makes this operation easier.

☐ 2 - It is then necessary to synchronize audio files with each other, which allows them to be replayed together. A quick listening to the tracks, first individually then simultaneously, makes it possible to quickly identify some anomalies such as full or partial absence of audio data on some tracks (see § 4.1), phase shifts (see § 4.6) or time stretching (see § 4.8).

☐ 3 - Listening to the whole file makes it possible to check the quality of the recording. It is especially important to check if crew members' speech is intelligible and if noises and warnings are audible.

When the signals do not show obvious anomalies, (see § 4.1 and § 4.2), it is acceptable to quickly browse the files, though passing slowly over high noise level areas (take off, landing…) or in low noise level areas to check the actual presence of audio data.

If some anomalies are present on the recordings, a more thorough and detailed check should be conducted.

4 - MAIN CVR ANOMALIES

The main anomalies identified by the BEA are:

- ❐ No audio data on one or more tracks;
- ❐ Poor quality of CAM recording;
- ❐ Interference;
  - ■ CAM recording pollution by aircraft power supply
  - ■ CAM recording pollution by CVR power supply
  - ■ CAM recording pollution by GSM pulses
  - ■ Audio popping on CAM track
- ❐ CAM recording saturation;
- ❐ Erroneous memory management;
- ❐ Phase shift between tracks;
- ❐ Level imbalance between tracks;
- ❐ Playback speed anomaly on an SSCVR.

In the rest of the document, each anomaly is described by:

- ❐ the impact on the CVR recording (anomaly characteristics);
- ❐ the methodology used to highlight it and check its presence on the recordings;
- ❐ non-respect of MOPS specifications from Eurocae documents.

4.1 No audio data on one or more tracks

This defect is characterized by a lack of useful audio data on one or more tracks on the CVR. It is immediately identifiable when listening and by observing the waveform (see Figure 2): only noise associated with aircraft power supply is audible.

This anomaly is the most negative for any work to be carried out on the cockpit voice recorder because it makes a valuable source of information for understanding the event unavailable to the safety investigation.

Reference specifications :

☐ ED 56A, §1.4.3.a

☐ ED 112 §I-1.3.3.a

Figure 2 - no audio data - waveform overview

4.2 Poor quality of cam recording

This anomaly can be caused by an intermittent malfunction of the CAM amplification box (Control Unit) or by poor electrical wiring throughout the CAM installation. The overall recording of the CAM signal may be of a very poor quality.

On listening, this defect leads to random variations in signal level: on some portions of the CAM track, the signal may have a very low level, or even non-existent – thus no audio signal (see figure 3).

This defect results in a loss of useful audio data on the CAM track (warnings, crew exchanges).

Reference specifications :
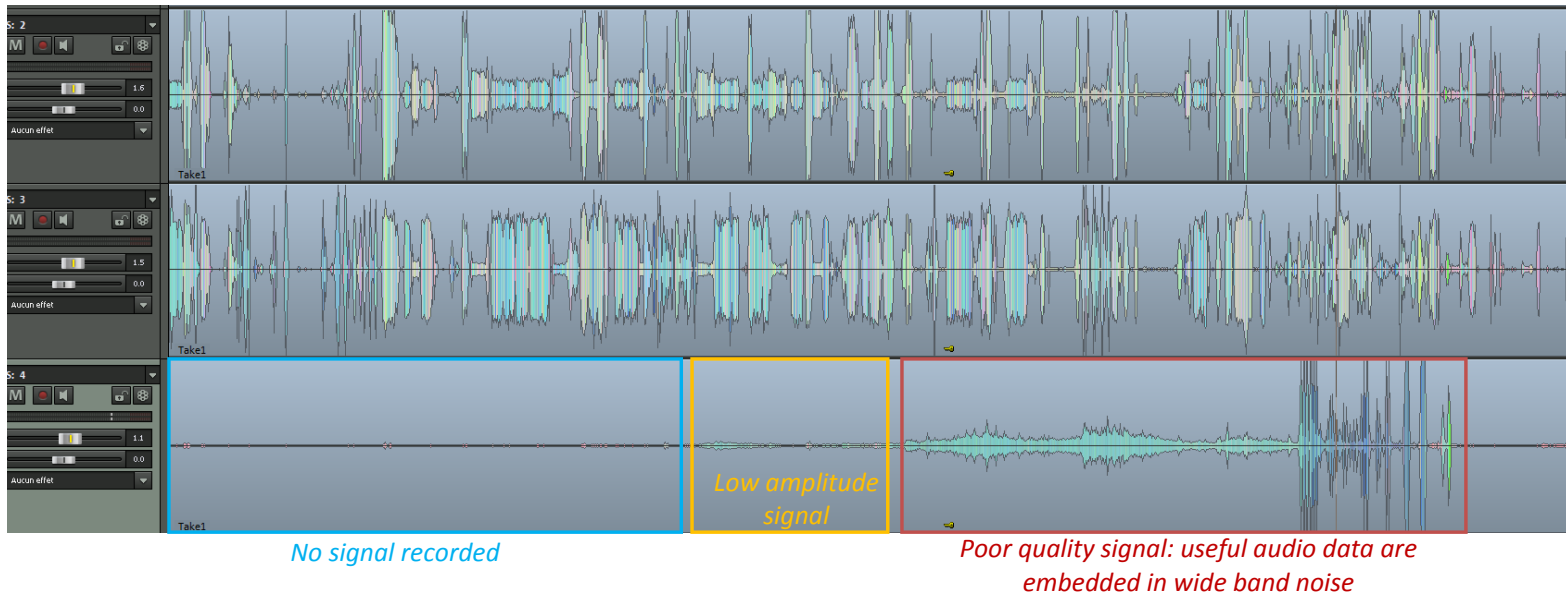
☐   ED 56A, §1.4.3.a;

☐   ED 112 §I-1.3.3.a.

Figure 3 - poor recording quality CAM track - waveform overview

4.3 Interference

Most of the interference detected in a variety of work carried out on CVR recordings has an electromagnetic origin and is due to:

❒ CAM recording pollution by aircraft power supply (pages 9, 10);
❒ CAM recording pollution by CVR power supply (pages 11, 12);
❒ CAM recording pollution by GSM pulses (page 13);
❒ Audio popping on CAM track (page 14).

Reference specifications:

❒ ED-56A, §6.2.5 -- ED 112, §2-5.3.5 b (effects of interference from other equipment);
❒ ED-56A, §1.4.3.a. -- ED 112, § §I-1.3.3.a (definition of the purpose of a CVR and its installation);
❒ ED-56A, §A.1.3.2 -- ED 112, §I-A.3.2 (no electrical interference).

4.3.1 CAM recording pollution by aircraft power supply

This pollution is characterized by the presence of a continuous parasite *"sound"* on the CAM track. The cases studied at the BEA showed that this sound was coming from the aircraft power supply. Listening is then very uncomfortable. This phenomenon appeared only on the cockpit area microphone track.

The presence of this anomaly on the recording can be confirmed by spectrum analysis (see Figure 5). This method reveals the presence of a harmonic family with a fundamental frequency moving around 400 Hz (between 340 and 490 Hz – aircraft power supply has a variable frequency for the cases studied). It appears that the greater the harmonic richness, the more severe the pollution will be and render any listening work difficult.

❒ Remark 1:
  ■ On some CVRs, the frequency causing the pollution is stable. It is then tolerated because it provides a useful time frame for the investigation (see ED 56A, §A.1.3.2, NOTE 1 or ED 112, § I-A.3.2.).

❒ Remark 2:
  ■ Audio signal listening and waveform observation make detection of this anomaly possible but are not sufficient to prove its presence (see Figure 4). The use of spectrum analysis is essential.

❒ Remark 3:
  ■ It is possible to use signal processing tools to filter this frequency and its harmonics. However, this technique may be difficult to implement because the fundamental frequency of the noise varies during flight. In addition, such filtering should be done with care and precision because if the pollution covers elements of the acoustic signature of the aircraft, removing it entirely (fundamental and each of its harmonics) can cause the loss of information essential to the investigation.

This interference causes listening discomfort which decreases the performance of the person responsible for carrying out the transcription work. In addition, when this pollution is severe, audio data present on the CAM track are hardly usable, especially conversations between crew members. However, it should be emphasized that regarding listening comfort, ED112 does not mention any restrictions or limitations on the level of the recorded signal as long as it does not exceed the recording capability of the whole CVR installation.
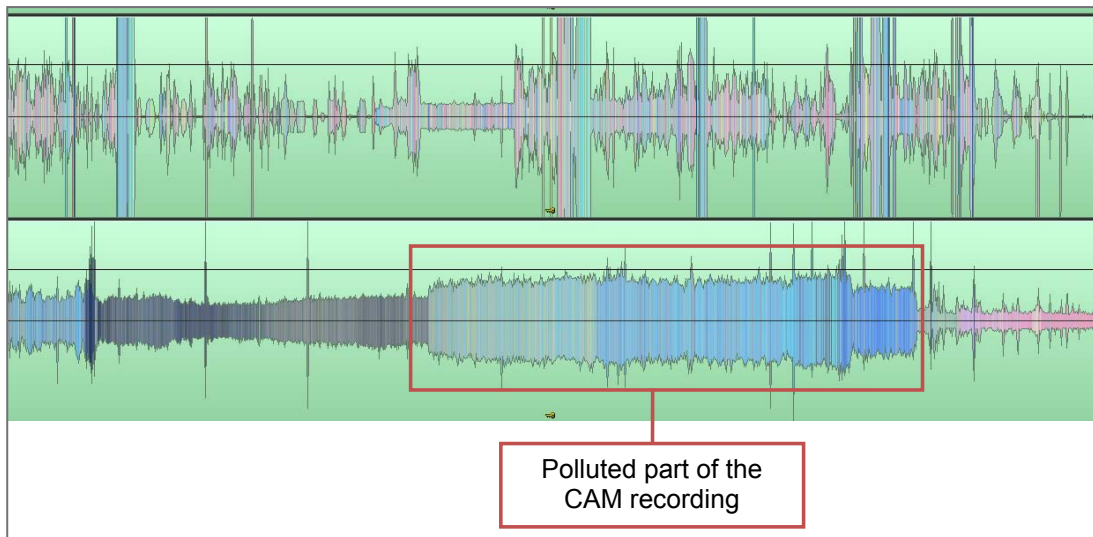

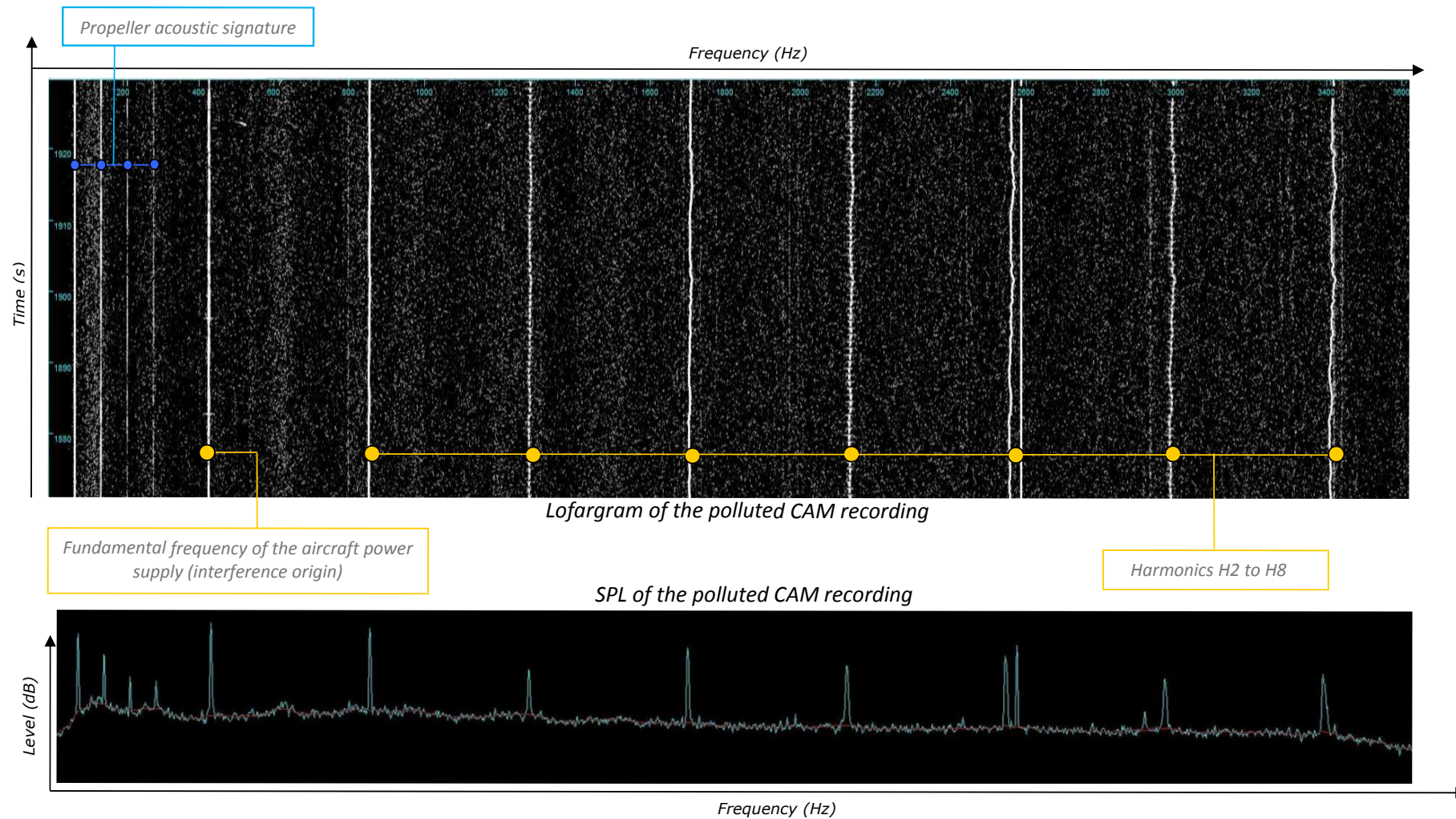Figure 4 - CAM recording pollution - waveform overview

Propeller acoustic signature

Frequency (Hz)

Time (s)

Lofargram of the polluted CAM recording

Fundamental frequency of the aircraft power supply (interference origin)

Harmonics H2 to H8

SPL of the polluted CAM recording

Level (dB)

Frequency (Hz)

Figure 5 - CAM recording pollution - spectrum view (Lofar et SPL)

4.3.2 CAM recording pollution by CVR power supply

This type of pollution can be described as a high level wideband noise (continuous whistle) whose centre frequency fluctuates slightly according to the flight phase. The width of this band is approximately 300Hz. This phenomenon appears when the CVR starts and disappears when the usual power supply of the device is cut off (transition to RIPS[6]). This interference is generated by the electric power supplied by the CVR to the preamplification module (Control Unit).

This anomaly is easily detectable because it makes listening work quite uncomfortable. The presence of this type of pollution can be confirmed by a spectrum analysis (see Figure 7).

❒ Remark 1:
  ▪ Like the previous defect, audio signal listening and waveform observation make possible the detection of this anomaly but are not sufficient to prove its presence (see Figure 6). The use of spectrum analysis is essential.

❒ Remark 2:
  ▪ Depending on the value of the centre frequency, it may be possible to remove this noise by using a notch filter. However, such filtering should be done with care because if the pollution covers over some elements of the aircraft's acoustic signature, removing it can cause a loss of information essential to the investigation.
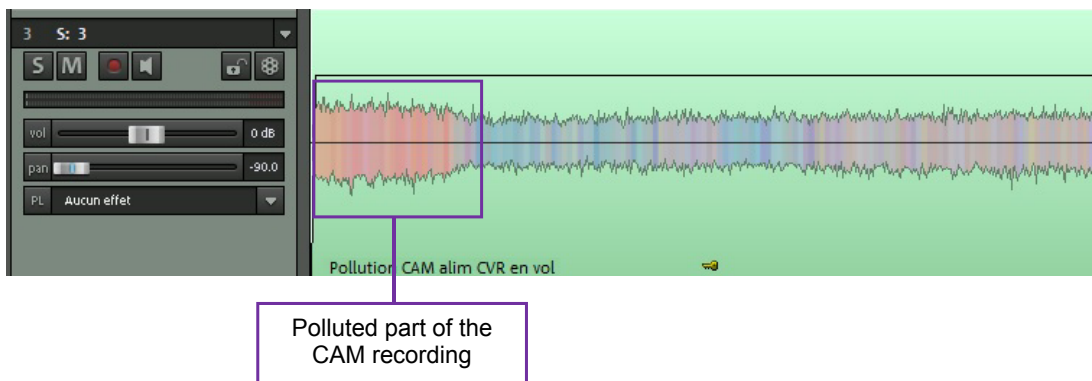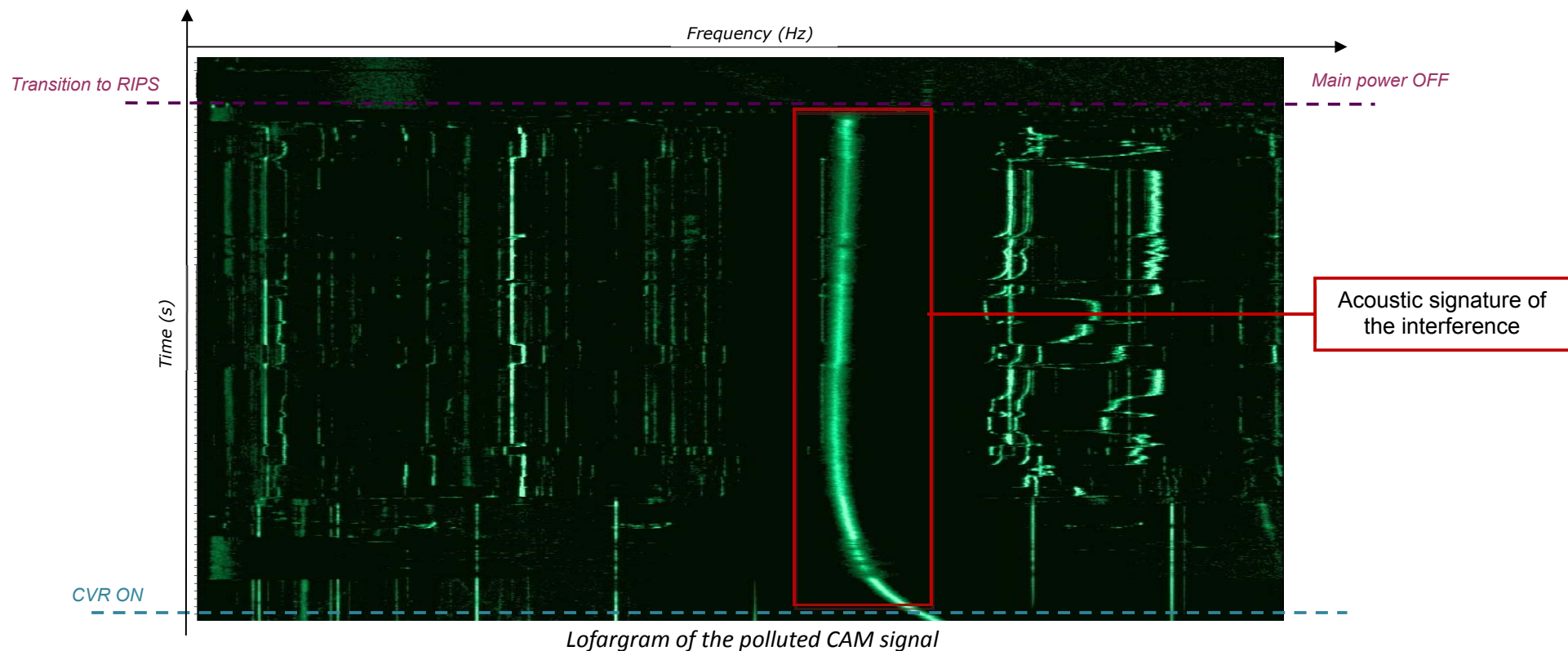

Polluted part of the CAM recording

Figure 6 - CAM recording pollution - waveform overview

Frequency (Hz)

Time (s)

Transition to RIPS

Main power OFF

Acoustic signature of the interference

CVR ON

Lofargram of the polluted CAM signal

Figure 7 - CAM recording pollution - Spectrum view (Lofar)

4.3.3 CAM recording pollution by CVR GSM pulses

This anomaly is characterized by the presence of interference on the CAM track. Depending on the level of the transmission, such interference may cause poor perception or even total masking of cockpit conversations. This defect can be detected by listening to the audio recording. A spectrum analysis will confirm its presence (see Figure 8).
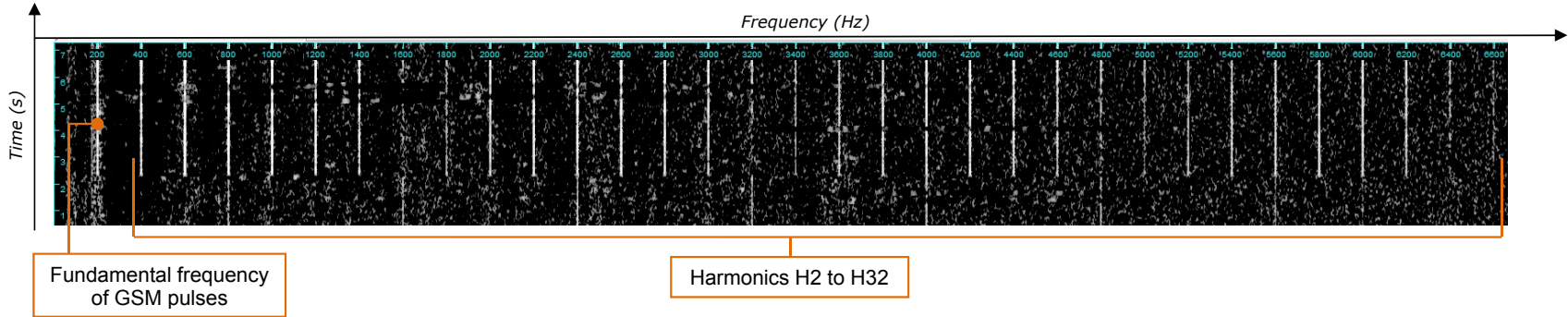
Frequency (Hz)

Time (s)

Fundamental frequency of GSM pulses

Harmonics H2 to H32

Figure 8 - CAM recording pollution by GSM pulses - spectrum view (Lofar)

Remark: the interference generated by GSM[7] pulses depends on the frequency used (eg, 450 MHz, 900 MHz, 1800 MHz, 2.4 GHz). This pulse is transmitted every 4.6 ms. This periodic transmission produces, on the CVR acquisition installation, an audible signal whose fundamental frequency is 217Hz and some harmonics.
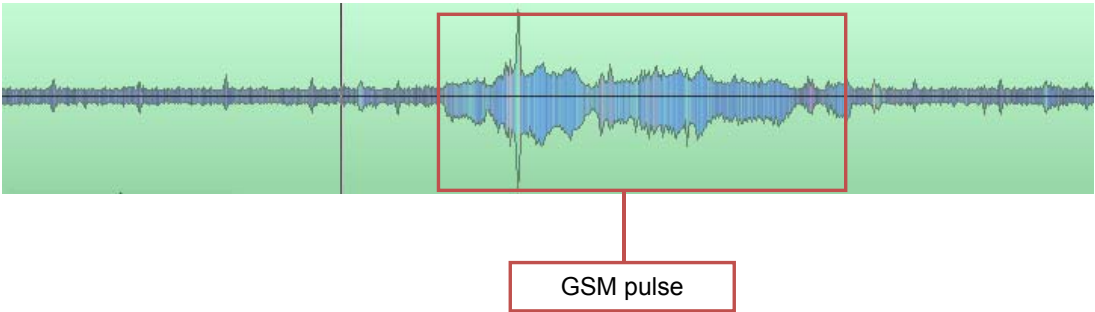
GSM pulse

Figure 9 - CAM recording pollution by GSM pulses - waveform overview

[7] GSM: Global System for Mobile communication.

4.3.4 Audio popping on CAM track

This problem appears when listening as a succession of *"pops"* on the CAM track. It is due to the sensitivity of the directional microphone or the Control Unit to electrostatic discharges (radiation). This event is predominant and easily identifiable on the waveform (Figure 10): It is similar to a succession of peaks, reaching the electric saturation point of the microphone.

The defect becomes apparent with a spectrum analysis (see Figure 11): it may look like a series of «peaks» with variable levels of energy. The frequency of occurrence of these peaks is irregular: they may appear quasi-periodically or completely erratically.
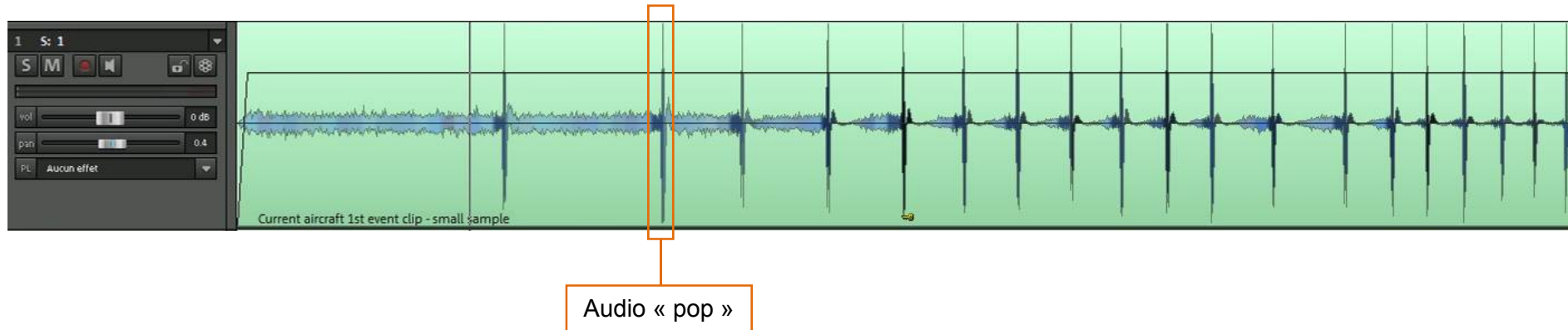

Audio « pop »

Figure 10 - audio popping on CAM recording - waveform overview
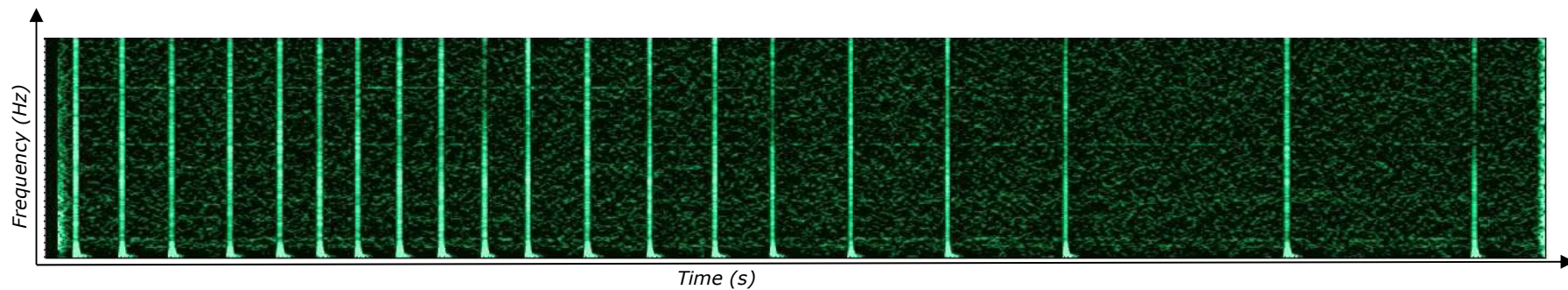

Time (s)

Frequency (Hz)

Figure 11 - audio popping on CAM recording - spectrum view (Sonar)

4.4 CAM recording saturation

This saturation is due to an excessive sensitivity of the CAM to low frequency signals. This saturation is acoustic, not electrical, because observation of the waveform indicates that the signal does not reach the maximum amplitude allowed by the CAM (no clipping on the waveform) (see Figure 12). When listening, the recording is indeed saturated and all relevant audio signals (conversations, warnings, callouts) are covered by the low frequency noise.

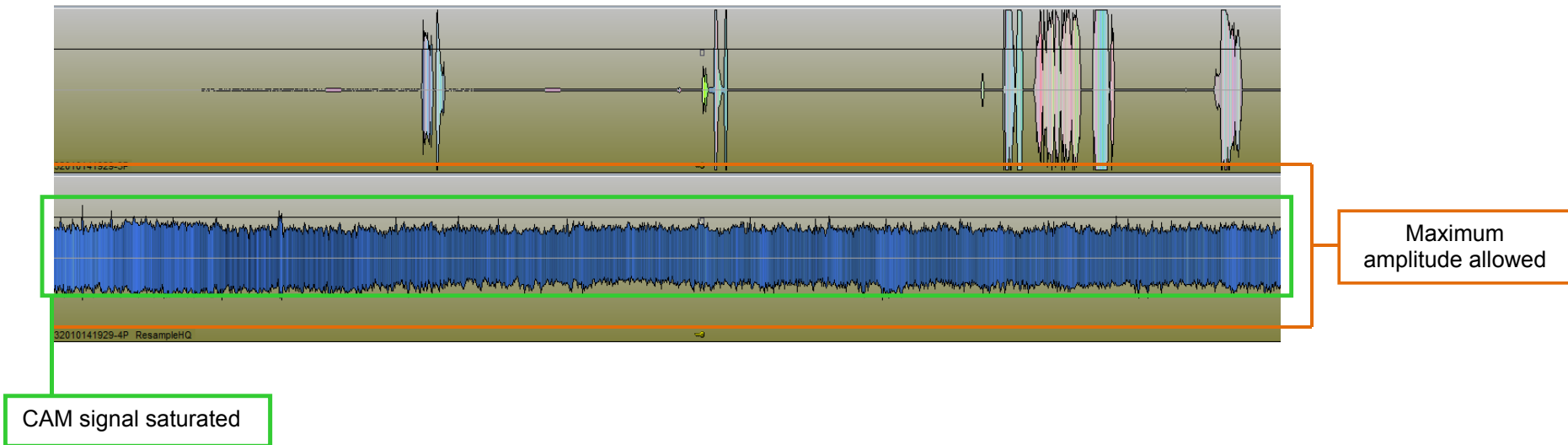Maximum amplitude allowed

CAM signal saturated

Figure 12 - CAM recording saturation - waveform overview

A spectrum analysis makes it possible to reveal this anomaly. In the example below (Figure 13), a harmonic family with fundamental frequency of 80 Hz (probably the acoustic signature of the aircraft propeller) is present. An SPL shows that this low-frequency harmonic family has a clearly predominant level compared to the general level of the CAM signal. This high level of energy is the cause of the acoustic saturation.

This interference causes listening discomfort which lowers the performance of the person responsible for carrying out the transcription work. However, it should be emphasized that ED112 does not mention any restrictions or limitations on the level of the recorded signal as long as it does not exceed the recording capability of the whole CVR installation. However, in an evaluation of CVR recordings, it is essential to draw attention to this problem when it occurs.
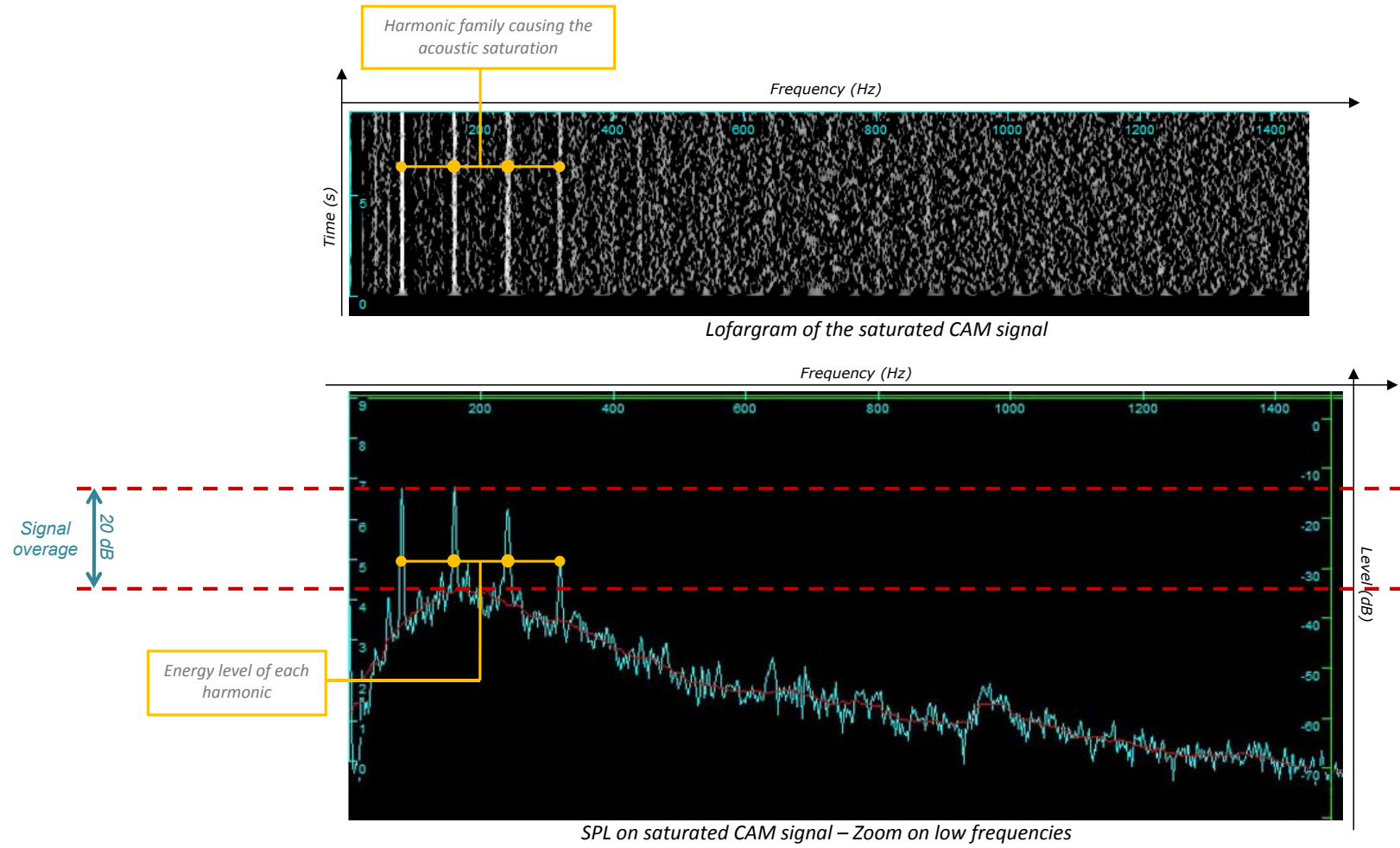
Harmonic family causing the acoustic saturation

Frequency (Hz)

Time (s)

Lofargram of the saturated CAM signal

Frequency (Hz)

Signal overage

20 dB

Level (dB)

Energy level of each harmonic

SPL on saturated CAM signal – Zoom on low frequencies

Figure 13 - CAM recording saturation - spectrum views (Lofar and SPL)

4.5 Erroneous memory management

This anomaly is characterized by a deformation of the audio signal. In some parts of the recording, the signal becomes unintelligible and includes *"electronic noises"*. It may happen that some parts of the signal have very low amplitude and sometimes a total lack of audio data (audio blanks).

This problem can be quickly identified by observing the waveform of the CVR recording (see Figure 14), observation confirmed by listening to the audio data. Generally, the waveform presents *"blanks"*, significant differences in amplitude on the same track (alternation of saturated signal and low amplitude signal). This defect often makes CVR recordings unusable, causing partial or total loss of audio data.

Reference specifications:
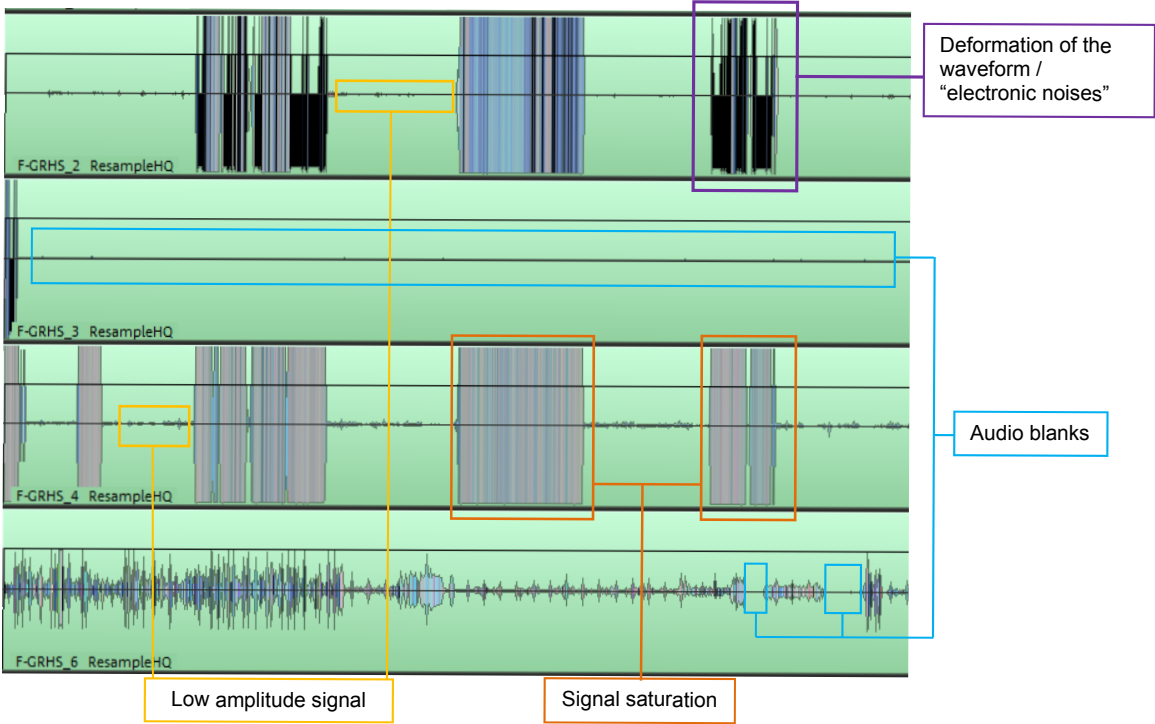
- ED 56A, §3.2.1 and §A2.3
- ED 112, §I-2.1.3.

Figure 14 - erroneous memory management - waveform overview

4.6 Phase shift between tracks

It sometimes happens that some audio signals (crew conversations, warnings, ATC communications, etc.) are not recorded with the same phase on each track of the CVR. This phase shift is particularly troublesome when it is 180°(opposite phase signals).

In practice, the same sound event (ATC message, warnings, etc.) will have weakened or even canceled amplitude if it is recorded on a mixed track on the CVR. The effect of this anomaly also appears when the tracks containing phase shifted signals are synchronized and played back simultaneously.

However, as the multiple signals received by the AMU have different amplitude, the result of phase shift will mostly be a strong attenuation of the signal.

This anomaly can be detected in several ways:

❒ if the CVR has a mixed track, observation of the waveform and listening to the audio content on that track will reveal the defect immediately, especially if the other tracks have *"normal"* waveforms;

❒ if the CVR does not contain a mixed track, listening simultaneously to all the CVR tracks once synchronized will reveal the anomaly: signals present on both tracks will have low amplitude. A comparison of each track's waveforms will confirm the «diagnosis». Better detection is possible by enlarging the track waveforms where a noticeable event is recorded (ATC messages, warnings, transient high amplitude signals). The phase shift will be more visible at this location.

This anomaly is similar to a loss of audio data and is detrimental to any analytical work on audio recordings, particularly if some of the information useful for the investigation can be found only on the mixed track.

Reference specifications :

❒ ED 56A, §1.4.3.a
❒ ED 112, §I-1.3.3.a

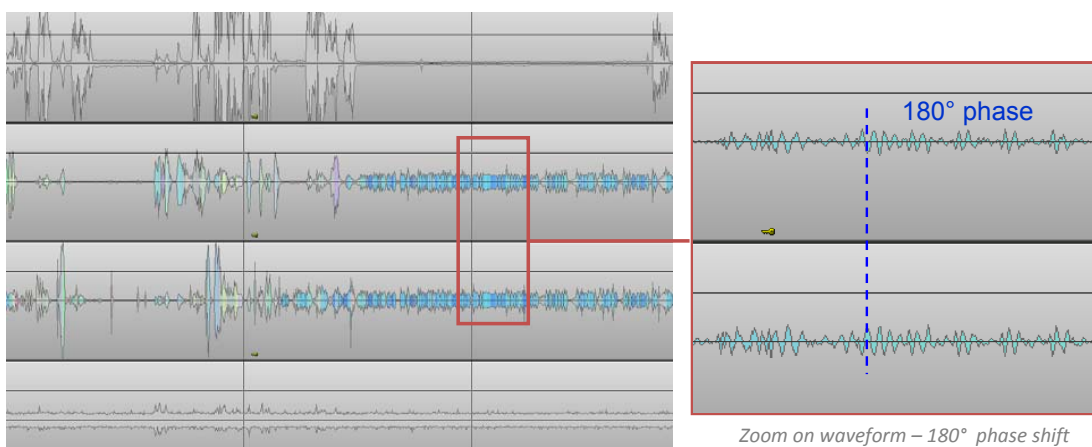*Zoom on waveform – 180° phase shift*

Figure 15 - audio signals in opposite phase - waveform overview

4.7 Level imbalance between tracks

This anomaly is characterized by a level difference between the input signals, particularly with regard to the level of ATC communications. In the following example (Figure 16), the ATC message is strongly attenuated on the second track (circled in red), and is almost inaudible.
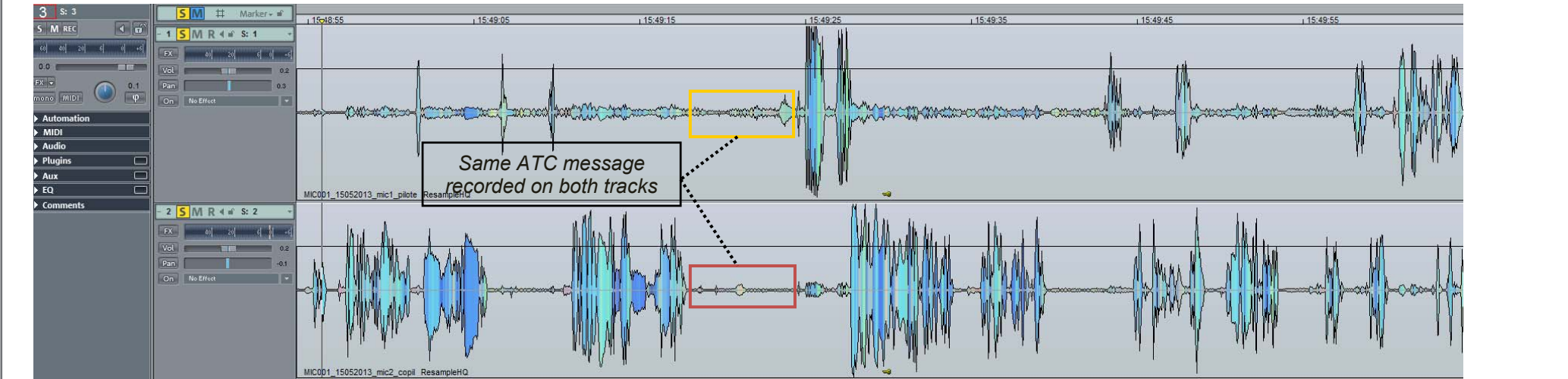

Figure 16 - level imbalance - waveform overview

This defect is detected by observing the waveform of the signal on each track. It can be confirmed by listening to each track separately, the difference in level can then be easily detected.

Reference specifications:

❑   ED-56A - §3.2.5
❑   ED112-§ I-3.2.2 (RSL < 3dB)

4.8 Playback speed anomaly on a SSCVR

This anomaly has only been encountered once at the BEA. During normal playback, the audio data downloaded replayed slower than the original data (audio content slowed down). This defect was due to a problem during the signal sampling.

This fault has no influence on the quality of audio data but on the precision of the retrieved audio content. It is noticeable only when the audio must be synchronized with other information (FDR, radar data, for example). Then, resampling is necessary (patching coefficient used on the playback speed).

This anomaly can be detected and highlighted in two ways:

❑ Inconsistency of the FSK[8] signal if it is recorded on the CVR. If the interval of 4 seconds is not respected (uncertainty included), the data downloaded can be suspected to not be replaying at the same speed as the data originally recorded. For the measurement to be significant, measure the interval between two distant FSK peaks on the CVR track and compare this interval with the theoretical value.

Example (see Figure 17): There is theoretically 96 s (24 four-second gaps) between 25 FSK peaks. If the measured value of 25 peaks is not equal to 96 s, then the fault is present on the CVR.

❑ Inability to synchronize the CVR and the FDR using events recorded both on the CVR and the FDR (VHF keying, warnings).

96 secs between 25 FSK peaks

Tk 1 HQ_Public address

FSK signal

FSK Signal – Zoom on waveform

Figure 17 - FSK signal - waveform overview

[8]FSK: Frequency Shift Keying. Beep recorded every 4s (+/- 2ms) on one track of the CVR (usually on the Public Address track and which encodes UTC time on 32 bits. This signal is recorded on ATR, Airbus (except A380 and A350) and Fokker 50 CVR 's).
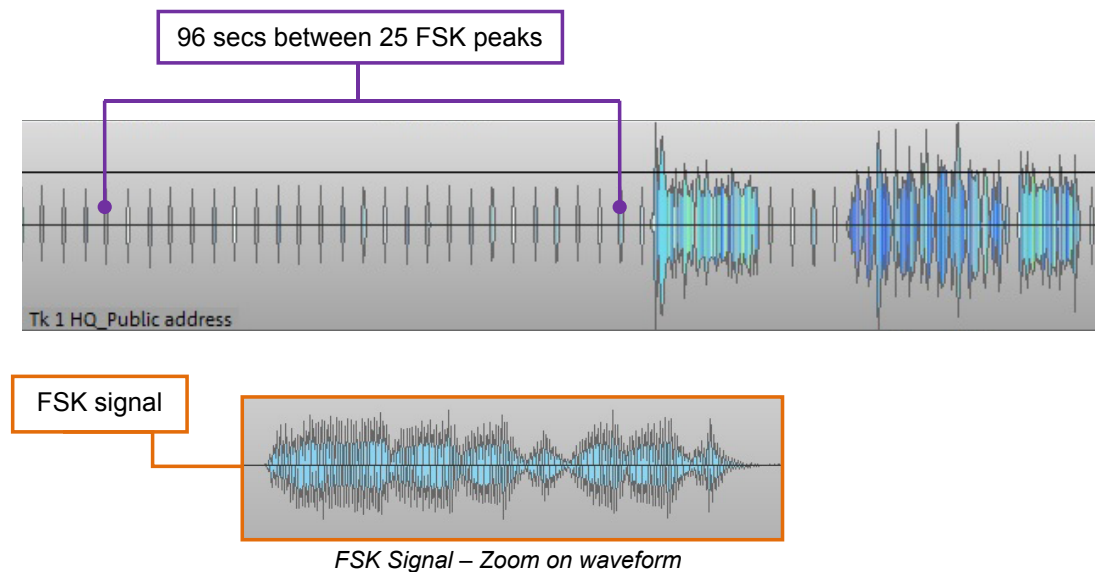
Case of time stretching

This anomaly has similar effects to a playback speed problem. The main difference is that audio tracks can't be synchronized with each other due to the sampling rate varying over time. Therefore, the application of a patching coefficient does not correct the problem and thus does not allow synchronized tracks to be obtained.

This anomaly presents several major problems:

❒ when retrieving audio data stored on the CVR, there is a loss of time correlation. Thus, the CVR is not compliant with ED-56A, §2.6.3 and ED 112, §I-2.1.3;

❒ the audio content does not precisely reproduce the data originally recorded;

❒ after resampling, the amount of recorded audio data is lower than the declared recording capacity of the recorder (eg 1h 56 min audio data instead of 2 hours). The CVR is not functioning to the performance specifications it should have, given the recorder class to which it belongs (see ED-56A, §1.4.2 and §2.6.7 - ED 112, §I-1.3.2 et §I-2.1.5);

❒ synchronization between the audio data from the CVR and flight parameters recorded in the FDR is impossible. The CVR is not compliant with ED-56A §2.6.4 and §3.4.2 -- ED 112, §I-2.1.4 and §2-1.11;

❒ no detection of this anomaly is possible if no FSK signal is recorded on the CVR, if the FDR is not available, or if the alteration of audio (pilot voice distortion for example) is not obvious (except in the case of time stretching).

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