Analysis

FIG 1. -STFT spectrogram

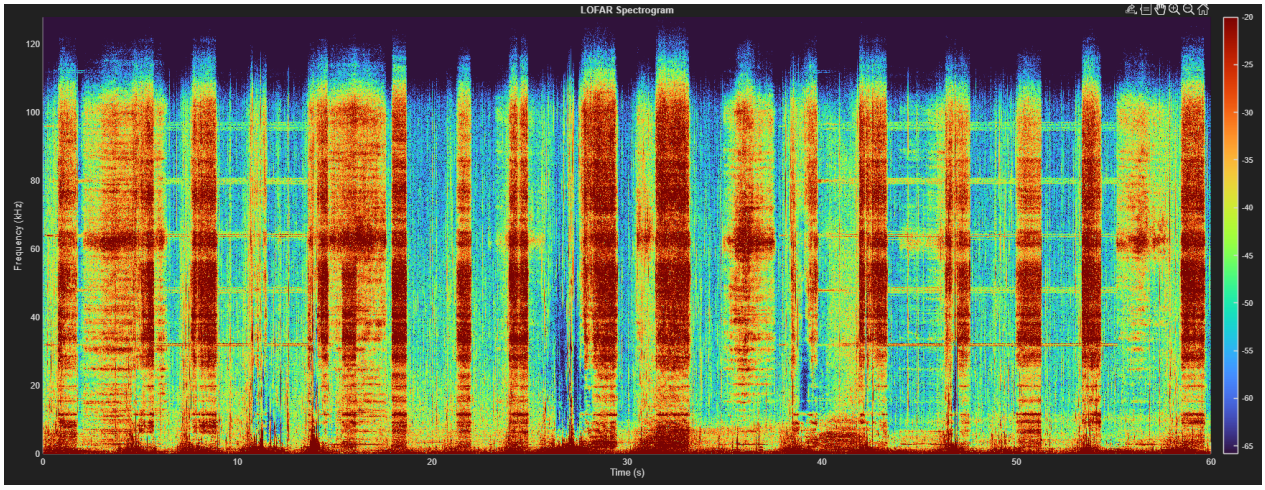
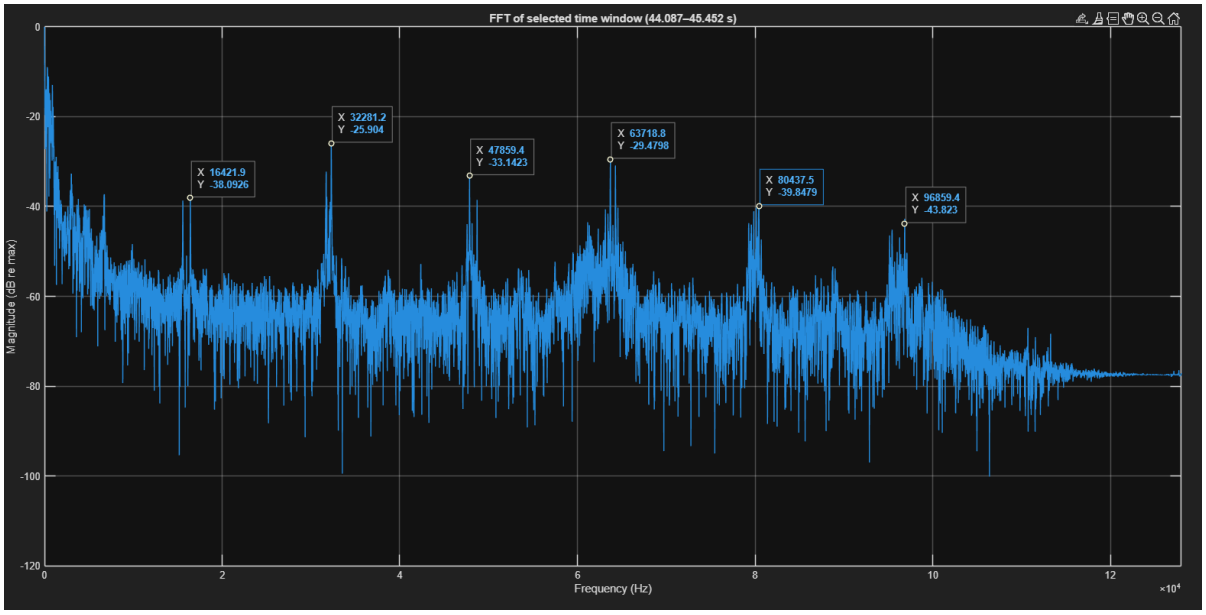


FIG 2. - Regional FFT 44-45 sec in the recording



- The prominent tonal is a 16 kHz line that appears with several harmonics (F1) – this is visible in the STFT spectogram and the regional FFT (FIG 1 and 2) – This in most likely attributed to a Pulse width modulation (PWM) of the electric motor – the PWM always displays a constant frequency with a varying duty cycle depending on the power output demand, i.e., in cases where the scooter motor is being used than this line should appear at a stable frequency and most likely increase intensity as speed of the motor increases (which is what we see in the STFT)

FIG 3 – Zoom in around 16 kHz (Harmonic no.3)

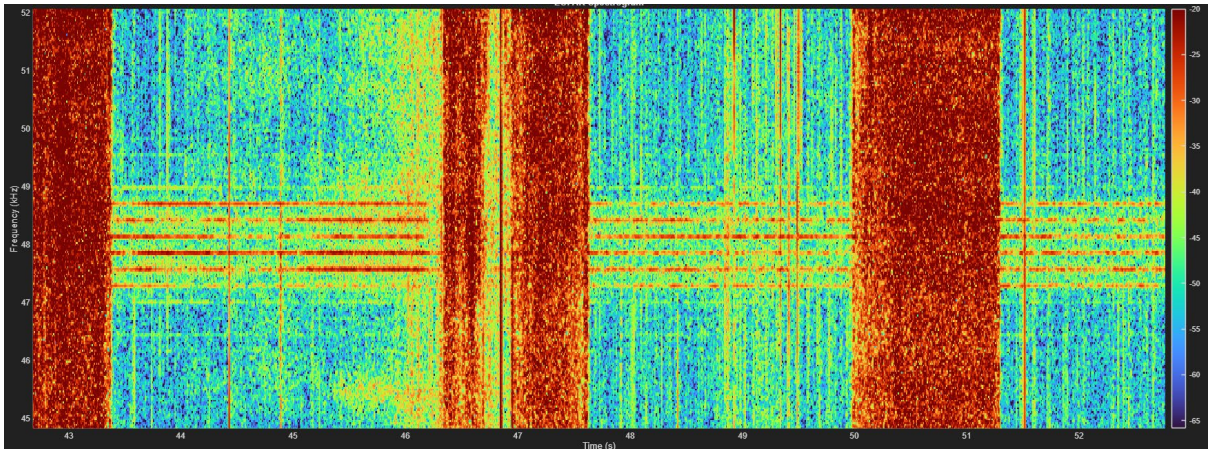
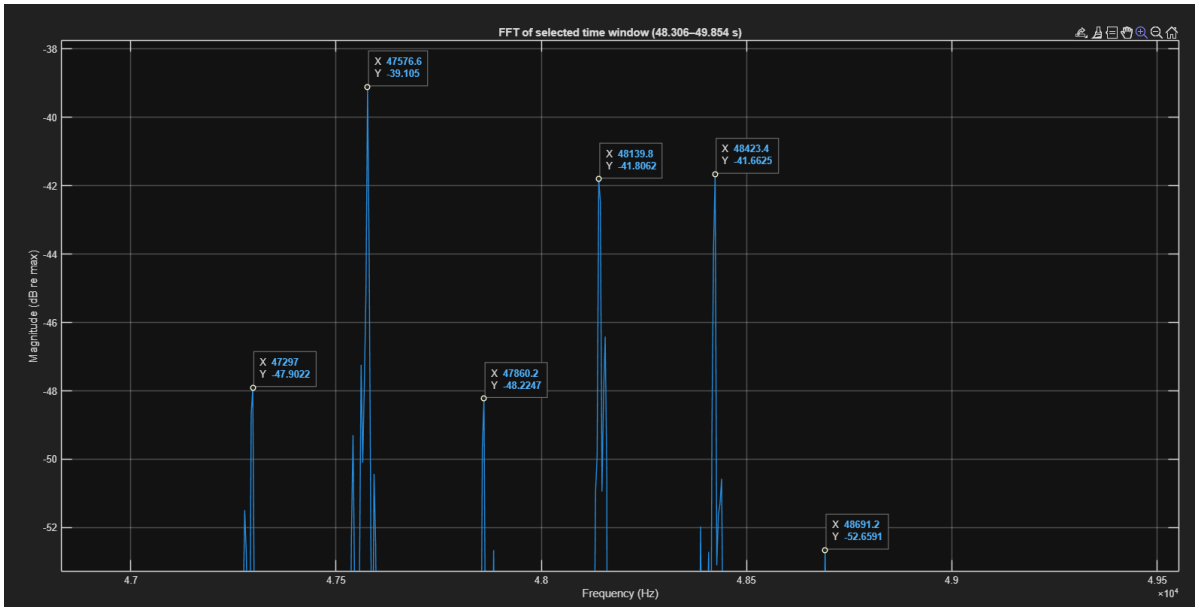


FIG 4 – Regional FFT around 48 khz



- As seen in FIG 3 and 4 there is a series of more tonal lines which are centered around the 16 kHz tonal lines (as previously mentioned most likely PWM).
- The series harmonic spacing is 280 Hz~ at 48 seconds in the recording.
- This indicates a frequency modulation (F2) centered around the 16 Khz tonal lines – this is supported by the temporal harmonic spacing differences when the speed of the scooter changes as seen in FIG 5 and 6

FIG 5 – Speed increase at beginning of recording – 16 Khz tonal line and harmonics (F1) are stable but the modulation series (F2) increases harmonic spacing around F1 – an indication of a speed increase.

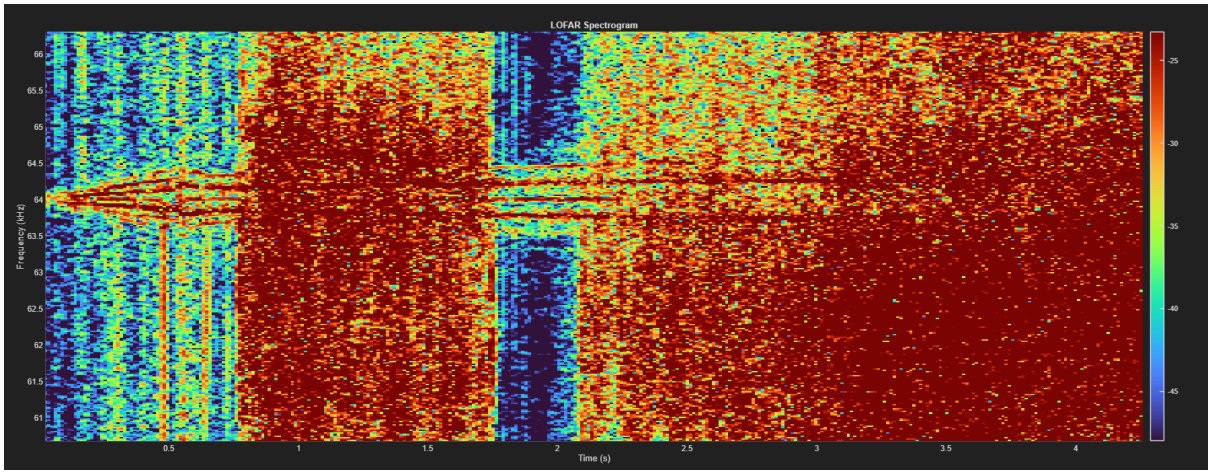
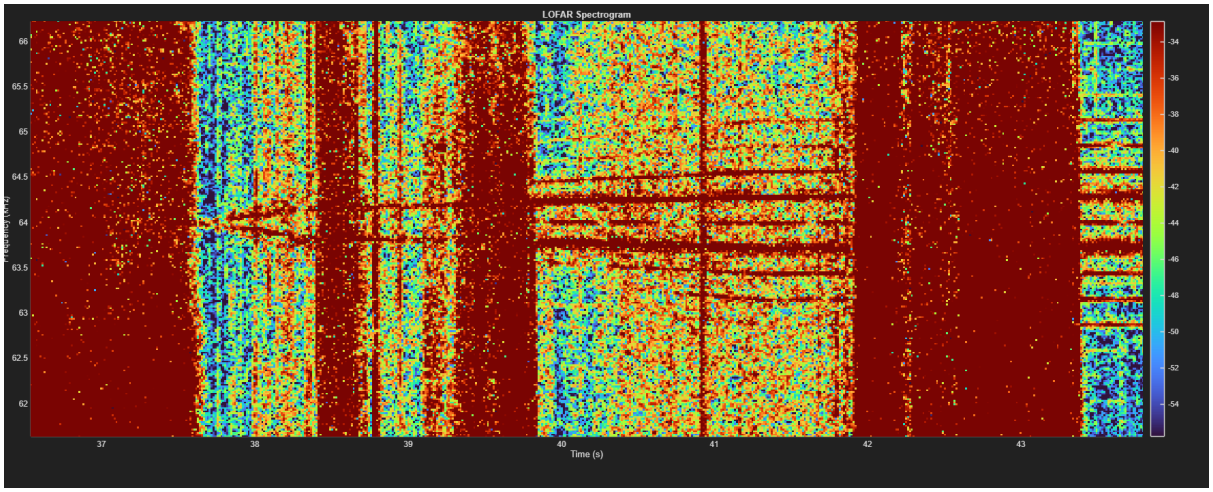


FIG 6 – an additional start of the scooter and speed increase at 38 seconds – same characteristics of FIG 5



- The modulated series (F2) is most likely resulting from the **number slots on the electric motor**

Summary

- The 16 Khz tonal lines (F1) are stable even when the speed of the scooter changes – this supports the PWM assumption as there is no connection between the motor speed and PWM frequency.

- The series modulation (F2) changes it harmonic spacing depending on the speed of the scooter which implies a connection between F2 and RPM of the motor – as the RPM of the motor increases the harmonic spacing of F2 increases and vice versa. As the rotational speed of 280 Hz is around 16800 RPM it is very unlikely this is a propellor or blade source. The most likely source is the number of slots in the electrical motor – as the motor turns the stator and rotor come into close proximity and the number of slots effects the noise signature:

  Motor RPM x no of Slots = Motor slot rate

  For example in FIG 7 an motor with 18 slots is present, for each rotation of the motor, the stator comes into close proximity with 18 slots creating a frequency series that is 18 times the motor speed.

  FIG 7 – electric motor generic scheme

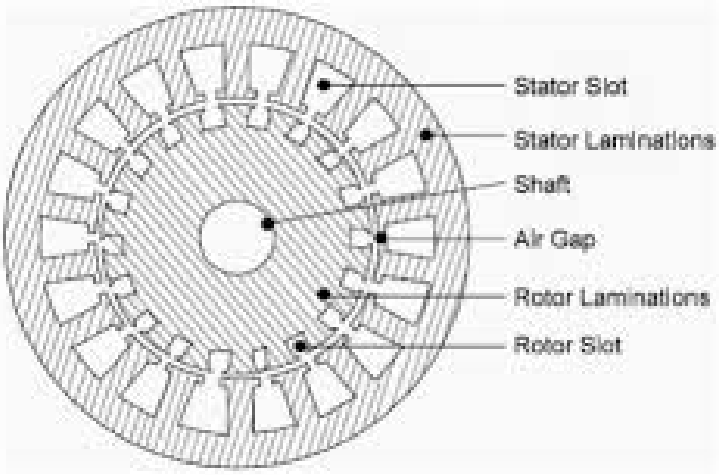
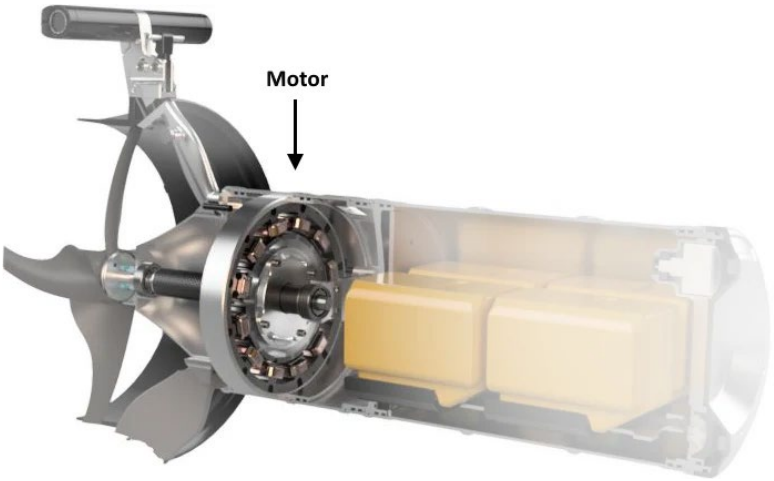


Fig. 11 Semiclosed slots

Fig 8 – examples of slots on electric water scooters



In this case the motor RPM is unknown (?) so we can assume the number of slots in the motor by each speed step

Speed step	RPM	Slot number
1	438	38
2	522	32
3	612	27
4	702	24
5	786	21
6	876	19
7	966	17
8	1050	16

A lower number of slot is likely – However affirming this would require a disassembly of the scooter motor.