Audible amplitude modulation

results of field measurements and investigations compared to psycho-acoustical assessment and theoretical research

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Presentation includes:

- ✓ Background points
- ✓ Conclusions of the paper
- ✓ Review / replay of some of the data

(Cannot fully reproduce today due to background sound levels and limitations of the audio system available)

Amplitude Modulation background in UK

UK position

Denial it's a problem.

Cause is a mystery.

Argue it is difficult to predict.

Occurrence **rare.**

Our Findings

Straightforward to find.

Occurrence is common – All turbines cause it & long known as a complaint cause.

Looked at 75+ wind farms causing complaints

– AM cause of vast majority.

Measured at 11 wind farms + analysed data for 4 more

– All generated excess AM.

Amplitude Modulation background in UK

Approach to field investigation

- Visit when light to determine likely spots.
- Visit when a stable atmosphere but high winds at hub height.
- Observe and measure after sunset.
- Choose a location within 60 degrees of downwind line at 500m-1km (unless elevated ground).
- Ensure near ground wind speeds low / almost non-existent.
- Record 100ms LAeq with spectrum at each interval (0.4-10Khz).
- Record audio 24 bit and 48Khz (16 bit 44KHz could suffice).

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Factors identified by researchers supported by our measurements

Van den Berg

- Atmospheric stability
- Synchronicity effects
- Low frequency prominence

Oerlemans et al

- Cross wind peak to trough increases close to turbine

Di Napoli

- Importance of weather
- Measure at night
- 5-12dB(A) peak to trough

Bakker & Rapley

- Heightened Noise Zones occur
- Levels in zones vary 6-13dB
- Equipment location critical

Larsson et al

- AM prominence at greater distance
- Meteorology important
- Synchronicity
- Variations 6-14dB(A)
- Occurs most commonly evening and night

Lee et al

- All turbines can emit AM
- Spectrum varies due to angle and distance.
- Longer distances = increasing low frequency dominance
- 3-4dB(A) enhancement wind speed gradient significant

Wilson

- 3-4dB(A) enhancement when downwind and downward refraction significant.

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Main conclusions of field investigations at 11 wind farms

- **All wind turbines cause AM**.
- AM **occurs in heightened noise zones** (HNZ)
- Meter location & site observations need to mirror positions found during survey when AM occurring.
- **HNZ vary** with wind direction, synchronicity and meteorology (especially wind shear)
- **Some locations regularly experience higher AM** than others.
- **Crosswind AM** exhibiting large peak to trough values can arise **at significant distances** in excess of 400m.

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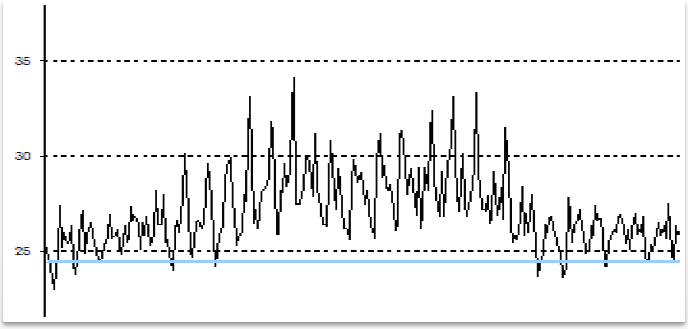
- AM exhibits a **range of features** / characteristics.
- Heightened peak to trough occurs typically for 6-20 seconds, subsides and rises again (**erratic and sudden changes arise**).



- The greater the **atmospheric stability the less variance** in the AM trace.
- Sometimes **high peak to trough values can continue many hours**. Likely under steady wind direction, wind strength and when stable atmosphere.

Spectrum of AM depends on

- Distance from turbines
- Meteorological effects - the extent of refraction,
- Synchronisation of separate turbine emissions
- Frequency content emitted in the direction of the receiver.

Leads to a wide range of variations

Increasing lower frequency dominance within peaks at greater distances (approaching 1km+)

Spectrum (content and modulation) varies with distance, direction and meteorology

= complex interaction = complex sounds result & ever changing impact type and level.

- **Array of turbines** - Experience different spectrum AM from different turbines at the same time or in succession = **highly variable sound character.**
- Some characteristics **commonly repeated**
- Peak to trough values can exceed **10dB(A)** & 20dB (typically 10-15dB) in 1/3rd Octave bands (400-1000+m distance) .
- Modulation **less than 3dB(A) – can still be highly intrusive** as constituents may modulate dramatically = changing sound character greater than the level change suggests.

Coherence / synchronisation effects occur

- **Divergence** and partial coherence **changes over time** changing the noise character **increasing, perception** and impact.
- Complex change in spectrum common.
- The changing sound content = constantly changing notice-ability and impact.
- Many **characteristics not reflected in "A" weighted values which is poor measure of AM** and its psycho-acoustic characteristics.
- Changes in sound character are dependent on a complex interaction of meteorological factors.

Assessing acceptability of AM

If you identify “A” weighted peak to trough variations due to AM of the order of **3dB or more**, found in 100ms LAeq data it is **likely to reflect adverse impact**.

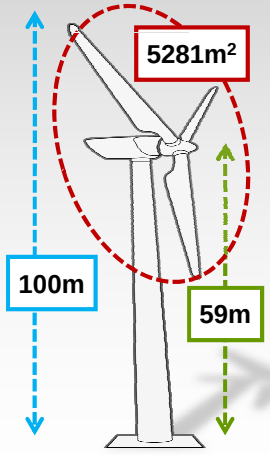
When variations of only 2-3dB(A) are measured, larger variations are also likely for large modern turbines.

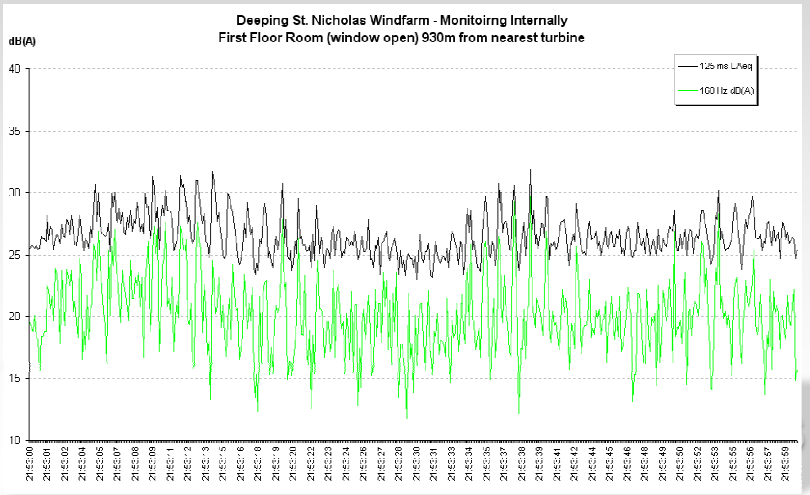
AM displays many features that attract attention both on a basic and complex level of auditory processing. Subjective and psycho-acoustic perception of AM is usually underestimated when assessing acceptability of wind farms.

Listening experiences and decision makers

- Decision makers need to experience the effects of AM to fully understand.
- As a substitute to living with it:
  - The Listening Room Experience discussed in the paper provides **a reasonable way of experiencing and understanding the impact**.

- **Can record internally** if use appropriate instruments and microphones with low interference.
- **Cannot reproduce suitably** when background is elevated or speakers do not have flat response.





11/09/2013

Listening to AM and interactive graphs

Any listening experience needs to be carefully constructed.

Cannot provide such an experience in the conference hall today due to:

Poor reproduction of the sound and LF content. Higher background – Masking of features and syncopation.

Example graphs played today and these slides will be on-line to listen to within 10 DAYS

See **http://www.masenv.co.uk/listening_room**