DETECTING ENVIRONMENTAL NOISE WITH BASIC TOOLS

By Henrik, September 2018, Version 2

Measuring low-frequency components of environmental noise close to the hearing threshold with high accuracy requires professional audio testers with a price tag of thousands of dollars.

By sacrificing a little in accuracy (from +- 1dB to maybe +- 5…10 dB), we can use either a standard smartphone or a handheld recorder in the 100- to 200-dollar category. The uncertainty factors stem from the lack of absolute level calibration, which must be deduced, and the inherent noise level of the gadget.

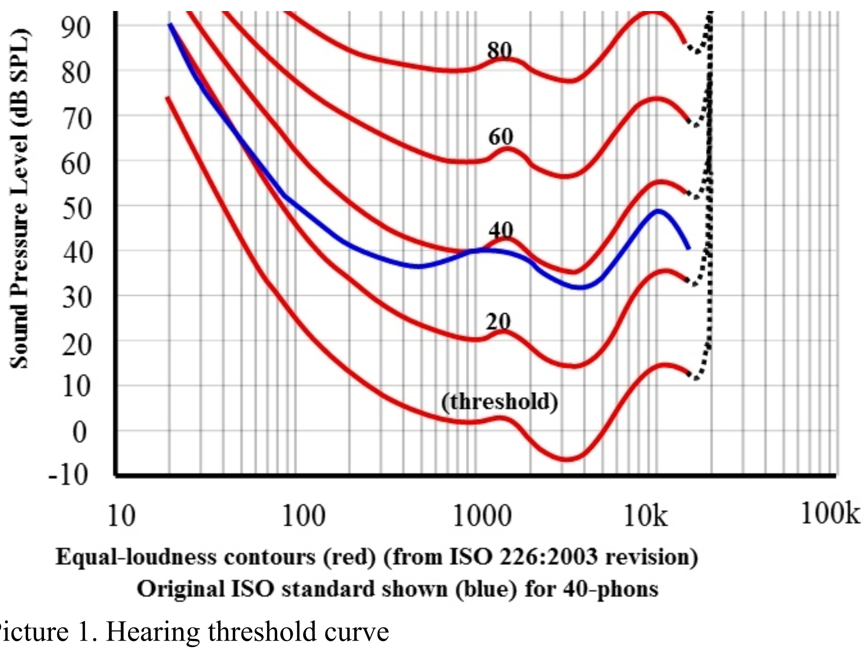
1. Using a Smartphone

These empirical (experimental) instructions are worked out using a Samsung SM-G530T phone and a Samsung SM-G313HZ phone, but are applicable to any Android-based smartphones. These instructions will be updated when we learn more.

The starting point is to install an app called "Spectroid for Android" from Google Play. There are many similar apps available, and these can probably equally well be adapted, using these hints as a reference. This app shows produces a spectrogram, where the vertical axis shows dBFS (decibels below Full Scale), and the horizontal scale is a logarithmic frequency scale. A logarithmic scale suits us well, because we are only interested in the lowest end, below 1000 Hz.

"Full Scale" means the highest sound level (in dB SPL = Sound Pressure Level) the microphone can stand without clipping. This point is not defined in the standards, but it basically means someone yelling into the phone at a few inches distance. What can be concluded from tests and reviews and other commentaries on smartphones is, that this level typically is more or less 112 dB SPL, give or take +-5…7 dB between brands. This means that a displayed tone of maybe -65 dBFS has an actual acoustic sound level of 112 – 65 = 47 dB SPL, etc. We now have a loosely calibrated absolute SPL scale. If you know the actual reference point for your specific phone, use that, otherwise use 112 dB SPL = 0 dBFS.

NOTE: Tablets usually have lower full-scale SPL (=higher sensitivity) since the microphone is not held near the mouth. They also often have higher internal noise, since they are not primarily intended for voice communication.



Picture 1. Hearing threshold curve

The standardized human hearing threshold for young people is defined in the standard ISO 226:2003 (See Wikipedia). For the frequencies we are interested in, the approximate single-tone hearing thresholds are:

Hz	**dB SPL**	**Age 50-60 years*)**
40	~50dB	>60dB
50	~42dB	>52dB
60	~37dB	>47dB
80	~30dB	>40dB
100	~25dB	>35dB
120	~20dB	>30dB
240	~10dB	>17dB

*) If you are 70 or older, expect to add another 5 or 10 dB to this hearing threshold, unless you have exceptional hearing.

The hearing threshold numbers for older people are empirical, and there are big variations between individuals. A hearing clinic's audiograms show inverted decibels referred to the nominal hearing threshold for young people, and they do not go lower than 250 Hz, so audiograms are of limited interest in this connection. If you have exactly the hearing of a normal young person, your audiogram is a flat horizontal line at the audiogram's "0 dB" level. Only if the 250 Hz point indicates some drastic deviation from "normal", you can assume that the effect is even bigger (in the same direction) on the lower frequencies.

The following settings in the Spectroid app have so far given the best results. Remember that we are looking for more or less continuous stable or slightly pulsating low-frequency sounds; we are not analyzing speech or music.

Audio:
Source: Microphone
Sampling rate: 11025Hz
FFT size: 4096
Decimations: 0 [=2.7Hz/bin; this is the frequency resolution of our spectral analysis.]
Window function: Blackman-Harris
Desired transformation interval: 100ms
Exponential smoothing factor: 0.95 (=Max)

Display:
Frequency axis scale: Logarithmic
Waterfall: Off
Max-hold trace: Off
Peak markers: Off
Stay awake: On

Miscellaneous:
Subtract DC: Off
Test signal: Off

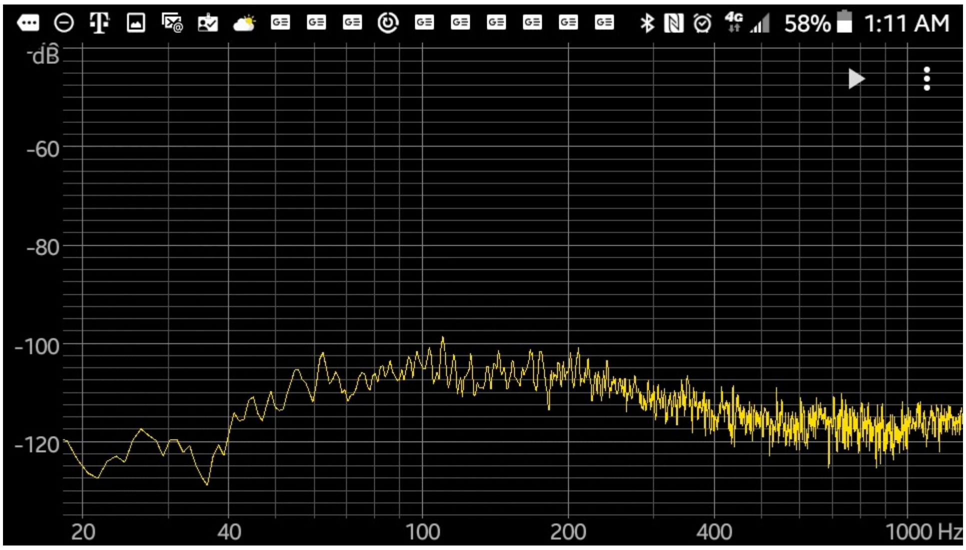
Adjust the screen (by two-finger moves and pinching/spreading) to show approx. 20(30)…1000(1200) Hz on the horizontal scale, and approx. -50…-120dB on the vertical scale. It is easier to adjust the vertical scale while in vertical screen mode, and the horizontal scale while turning the phone into horizontal mode. If some green "jumping" lines appear, click the "X" in the upper right corner of the screen. This adjustment takes a bit of patience, but the app remembers it once it is done.

Choose a time for recording when you hear your Hum loud and clear, in an otherwise quiet place.
Place the phone on a hard-cover book and place the book on a pillow on a table or a bed. The purpose of the pillow is to eliminate possible building vibrations being recorded, and the purpose of the book is to remove the microphone a little from the sound-absorbent pillow surface. Use horizontal screen mode for recording, since we are more interested in the frequency than the absolute levels. If you have a suspected

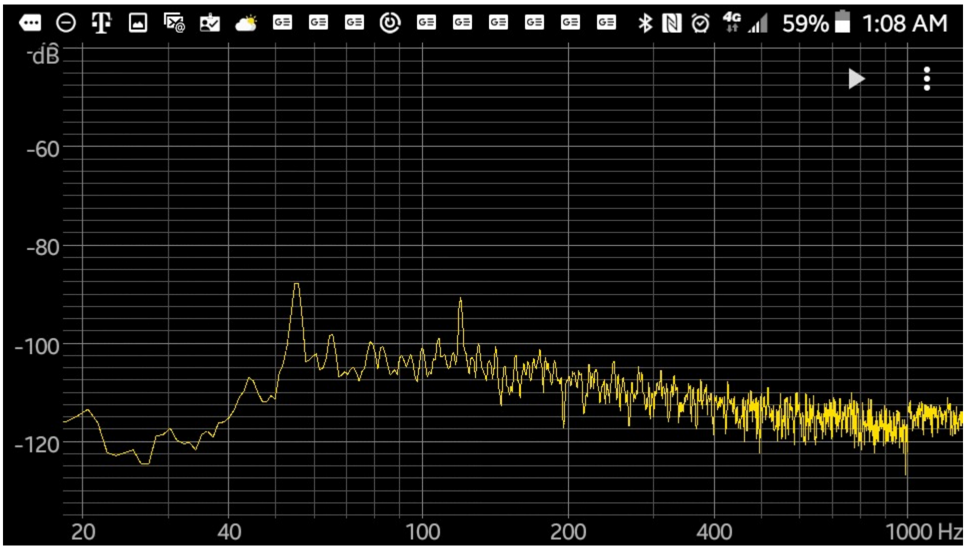
source of the sound, turn the microphone towards the source. The microphone in a smartphone is usually located behind a very small hole at the bottom edge of the phone housing.

Remove ticking clocks, and do not place the phone near electrical appliances in standby mode, like TVs or microwave ovens, or unplug such devices.

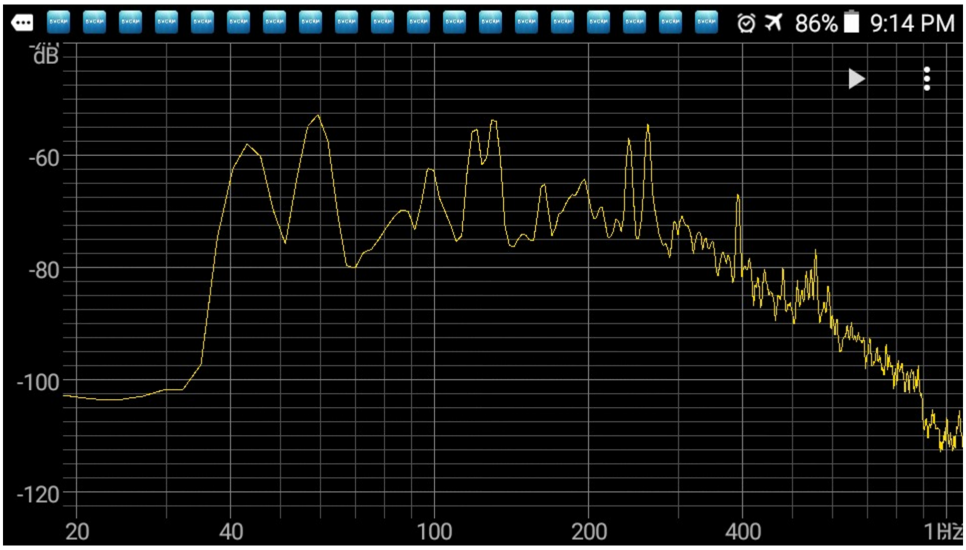
Be absolutely still and quiet, and observe the emerging spectrum picture. When you have a more or less stable diagram, click the “pause” symbol with a soft-tipped stylus to freeze the picture and store the screenshot. It should look something like Picture 2 in a very quiet room. In this case the main power distribution panel of the house was switched off.



Picture 2. Total silence



Picture 3. Distant fan sound, not audible.



Picture 4. Refrigerator running, fully audible

In **Picture 2** the noise levels (per 2.7 Hz of bandwidth) around 120 Hz are approx. -105 dBFS, which corresponds to 112-105 = 7 dB SPL. This lies below the hearing threshold even for a young person with perfect hearing.

In **Picture 3** the power was switched on at the distribution panel of the house, and it shows a small noise peak of -87 dBFS at approx 56Hz and another around 112Hz (most likely an exhaust fan). The first noise peak is attenuated by the low-cut filter of the phone by an estimated 5 dB, so the actual reading should have been -82 dBFS, which converts to 112-82 = 30 dB SPL. This is still way below the hearing threshold even with perfect hearing. The 112Hz peak is estimated to be affected by only 1 dB by the filter, so the actual levels should be approx. -90 dBFS, which converts to 112-90 = 22 dB SPL. This is just at the threshold for a person with perfect hearing, and 90% of all people would not hear anything.

Picture 4 is the screenshot of a refrigerator, where the compressor is operating. Here we can see the basic approx. 58 Hz sound from a motor running with 60Hz line power and having a slip of approx. 3-4%, and a second harmonic at around 116 Hz. Additionally we see miscellaneous mechanical sounds from the compressor, at approx. 43Hz, 98Hz, 130Hz, 230Hz and 260Hz. Note that the frequency scale is logarithmic, so mid-way between two lines is not 150% of the left grid line, but approx 141%. For example the 260Hz tone here is -55dBFS, which converts to 112-55 = 57 dB SPL, which at this frequency is "loud and clear" to anyone but totally deaf people. Also remember, that all audible tones add together by power addition, and it is the total SPL we actually hear, and call "loudness".

We can draw two technical conclusions from Pictures 2 and 3:

1) The internal noise of this device is barely low enough not to mask single-frequency acoustic signals close to the hearing threshold in the range we are interested in. [The noise we see comes from the electronics of the phone. If we would hear it through a loudspeaker, it would be a fully audible noise (hiss), because over the full hearing range up to 20,000 Hz, the cumulative noise over all frequencies would be approximately 20,000Hz/2.7Hz = 39 dB higher. Here we are chasing single low-frequency sounds, and comparing them to the hearing threshold at the frequency in question, so the broadband noise (S/N) inside the phone is irrelevant for these purposes.]

2) There is, like in most cellular phones, a low-frequency cut-off filter at the microphone with the purpose of reducing wind noise when using it outdoors. In this case this filter has a cut-off frequency of around 70-80 Hz, which means that this smartphone will show too low readings for very low-frequency environmental noises. However, most power-grid related "hums" are found at or just below 120, 180 and 240 Hz (Europe: 100, 150, 200etc.), so this is not a serious drawback.

We can also draw another important conclusion from Pictures 2 and 3, and the hearing threshold table: **If a person hears a "Hum" and the display looks like Picture 2 or 3, what that person "hears" at that instant is an internally generated hum.** That is the "final proof" of internally generated hum we have been looking for. In other situations the same person may hear external noises or mixtures of internal hum and external noises. Anything internally generated will vary in intensity, just like headaches and other bodily discomforts come and go. <u>All low-frequent environmental noises audible to the human ear</u> will, however, show up on the Spectroid screen.

The fact that a hum sensation in this way may be proven to be of internal origin does not exclude that it may be caused or triggered by some external influences, like earlier exposure to various forms of radiation, medication, auditory overload or other mechanisms. These are still open questions.

If the internal noise level of your phone in a totally silent environment is any higher than what is shown in Picture 2 above, that model may not be suitable for this purpose. Likewise, if the low-frequency cut-off of the microphone starts at 100 Hz or higher, that model may not be suitable. The model used above represents more or less minimum requirements for the results to be useful. The Samsung SM-G313HZ model has around 10dB lower noise and a cut-off of around 40 Hz, so the variations are big also within the same brand.

2. Using a TASCAM DR-40 Recorder

The TASCAM DR-40 handheld recorder is one of many similar affordable handheld recorders, popular among reporters and musical recording amateurs. Its noise performance is much better than that of any smartphone. If you have another recorder, just adapt these instructions to your model.

The TASCAM cannot accommodate any spectrogram app, so we have to make recordings, maybe 30-60 seconds in length, and then analyze the recording by using a spectrum analyzer app on a computer. We have here used Audacity, which is totally over-engineered for our purposes, but there are many other similar and easier-to-use apps available. You can use the hints below for settings in other apps.

One advantage of the TASCAM over a smartphone is that its microphones cover down to below 10Hz with the low cut-off filter disabled. It is therefore usable for investigating also very low-frequency hum phenomena, like traffic rumble. The TASCAM DR-40 recorder is, however, very sensitive to interference from cellphones. Keep your phone in another room while recording or put it in Airplane Mode to avoid distorting the audio recording.

The empirical best settings for the TASCAM appear to be the following. These will be updated if/when we get more experience or feedback. The recorder must be used as battery operated for this purpose.

Recording mode: MONO, WAV 24 bit, sampling rate 44.1 kHz (=lowest available)

LOW CUT: OFF (Options are OFF, 40Hz, 80Hz, 120Hz)
EFFECTS: OFF
LIMITER: OFF
LEVEL CONTROL: OFF (= manual volume control). This can be set only in mode "Record, Standby".
Manual level setting (on the left side of the recorder body): Exactly mid-position (check the numbered scale in the display and set it to 45).

[NOTE: The clipping point for the TASCAM DR-40 is given as 125 dB SPL, however, without mentioning at what volume setting. The manufacturer has been unwilling to confirm any specifications either by mail or telephone, so it is for the time being only my best guess, that 125 dB SPL ~ 0 dBFS with this setting. Side-by-side recordings with smartphones have confirmed that this assumption is not too far off.]

In Main Menu:
Pre-Recording Buffer: OFF
Auto Record: OFF
In Record Mode:

Rec. Mode: MONO
Source: Internal (INT)
Dual mode: NO
4-ch mode: NO
MS-decoding: OFF

Using this assumption, a reading of for example a 120 Hz hum of -75 dBFS now converts to 125-75 = 50dB SPL. This would be clearly audible both for a young person and also for anyone aged 50 to 60.

Transfer the recorded audio file to your computer, and open it with Audacity (File - Open). Choose the display mode "Waveform (dB)" and the correct sampling rate (44.1 kHz) and coding (24 bit) by opening the small menu button in the upper left corner of the graphic display window. Select the start point of the analysis by left-clicking on the recording graph, and then select the length using the "finger" pointer. Click stop (pause) if the file starts playing during this process. Do not select sections where there are sudden noises or clicks, since they will distort the spectrum analysis.

Go to Analyze – Plot Spectrum. Select the following settings at the bottom panels:

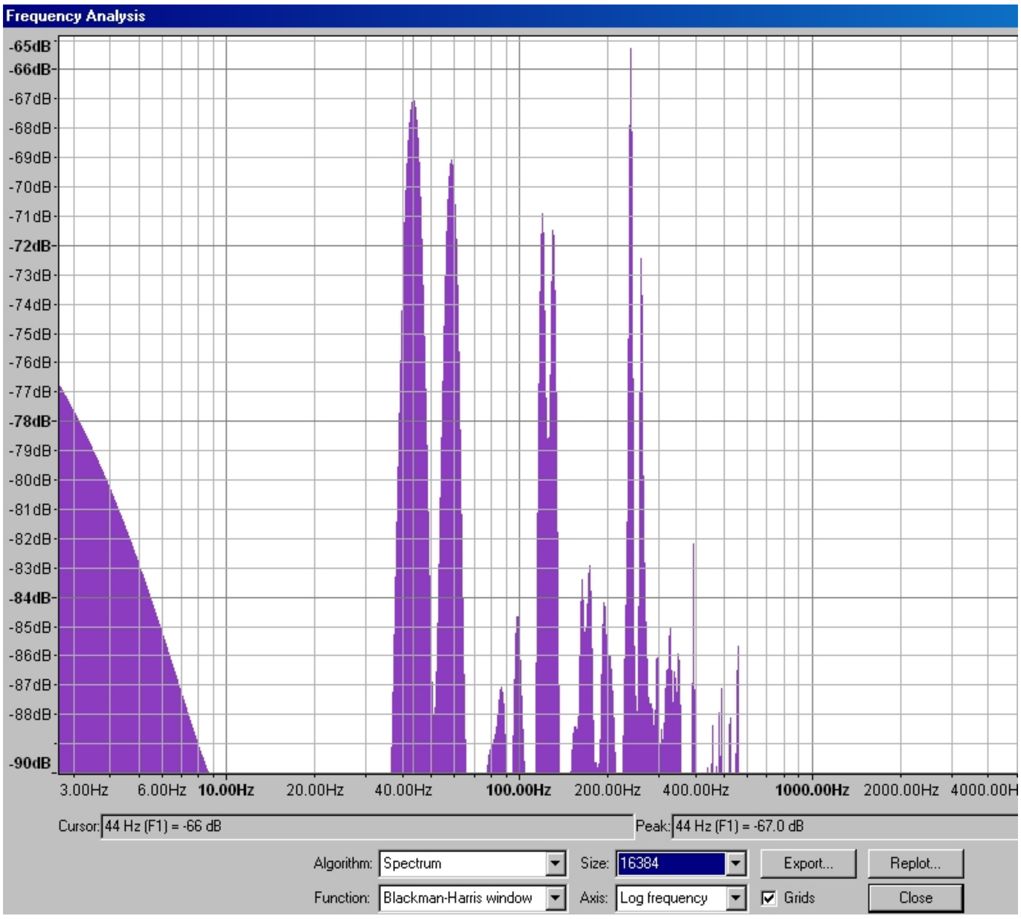
Algorithm: Spectrum.
Size: 16384 (With sampling rate of 44.1 kHz, this will generate the same frequency resolution as in the case of the smartphone above, or 44100/16384 = 2.69165 ~ 2.7 Hz/bin).
Function: Blackman-Harris window
Axis: Log Frequency

Move the spectrum window to the side and check that the start-stop points in the recording graph have not accidentally changed. If they had changed, close the spectrum window and select again and click Analyze – Plot Spectrum again. Now the spectrum graph shows the different frequency components with approximately correct amplitudes (approx. +-2 dB, assuming that the dBFS scale calibration is correct). To identify the exact frequencies of various hum components, change to Rectangular Window and use the cursor to find the peaks. The amplitudes are not correct with Rectangular Window, but the frequency is accurate. Identify the exact frequencies with Rectangular Window, and then read the amplitude using the Blackman-Harris window.

Save a screenshot of the spectrum while using the Blackman-Harris window. This is the best picture of what has been recorded, which we can obtain with this tool.

One limitation of the Audacity analysis window is that the lowest visible amplitude level is -90 dBFS, which converts to 125-90 = 35 dB SPL. This means that a -90 dBFS single-frequency sound above approx. 100Hz already reaches the hearing threshold. However, what we are trying to do is to identify low-frequency noises that "drive people crazy" or at least prevent them from sleeping. Something just above the hearing threshold would never be described in those terms. So if we find environmental sounds that disturb us, they will show up "loud and clear" at much higher levels than -90 dBFS.

Picture 5 shows the Audacity spectrum plot for the same situation as in Picture 4 (the recorder and the phone were side by side). We can determine the frequency components much more accurately in the Audacity plot by moving the cursor.



Picture 5. Audacity spectrum plot of the situation in Picture 4.

3. In summary

For detecting low-frequency noises and determining whether our Hum is internal or external, the smartphone solution is sensitive and accurate enough.

If we find an environmental noise, which we want to trace and possibly remedy, the recorder-plus-spectrum-analyzer method makes it possible to determine the frequency components more accurately, and distinguish between transformer sounds (exact multiples of the power line frequency) and acoustic noises from machines, which can be random for combustion engines, railways and factories, and fall just below the line frequency and its multiples for rotating electrical motors (due to the slip effect).