ELECTRONOTES

WEBNOTE 45 12/12/2016

ENWN-45

EDGE PITCH, TINNITUS, and the HUM

A Quick Look (and Listen)

It is "well-known" that human beings have hearing perception running from 20 Hz to 20 kHz - or something like that. Clearly this sort of engineering specification as applied to a flesh-and-blood mechanism is at best an approximation. Different people will have different hearing curves, and these will change with time (generally the range and sensitivity gets less with age). Perhaps the general idea of what we find is shown in Fig. 1 where we have inverted a standard "Fletcher Munson" (FM) curve [1]. Very roughly, this is a wide band-pass from about 100 Hz to 10 kHz. Many times (most times) we are accustomed to a band-pass filter as a sharp narrow peak favoring one frequency. Here we call it a "wide band-pass" to suggest an extended passband which in the FM curve is not especially flat (well, it's not engineering!).

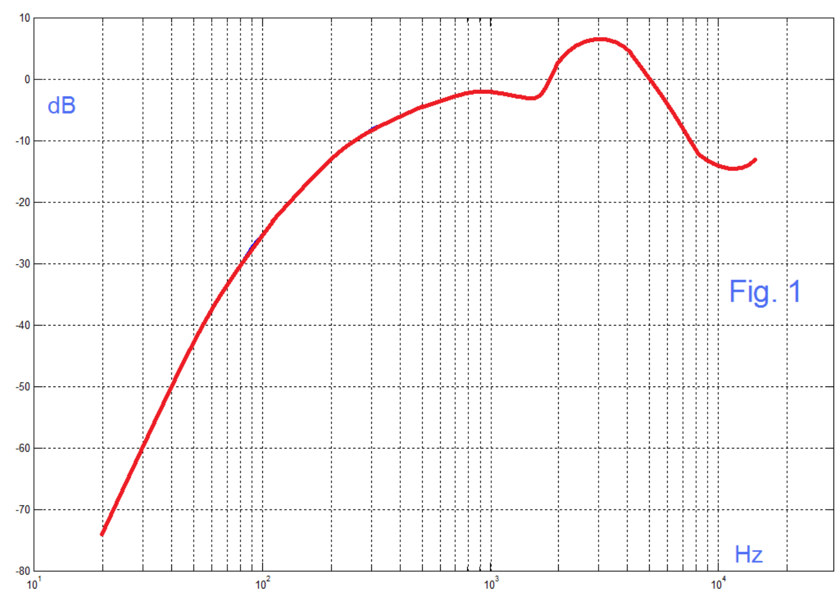
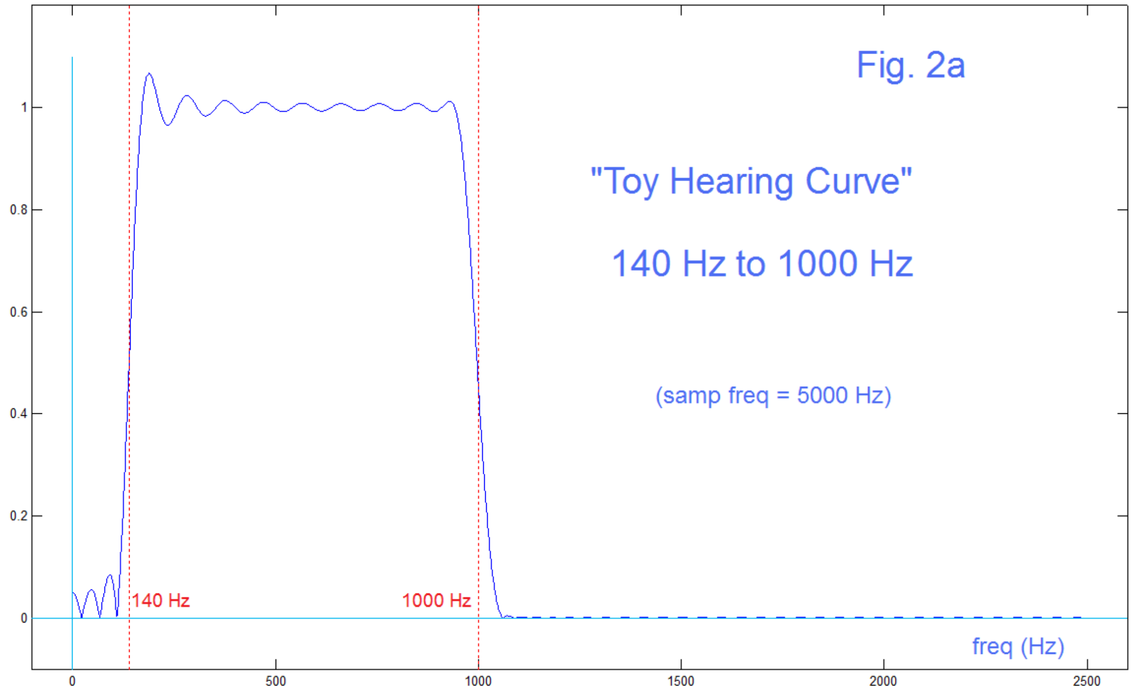
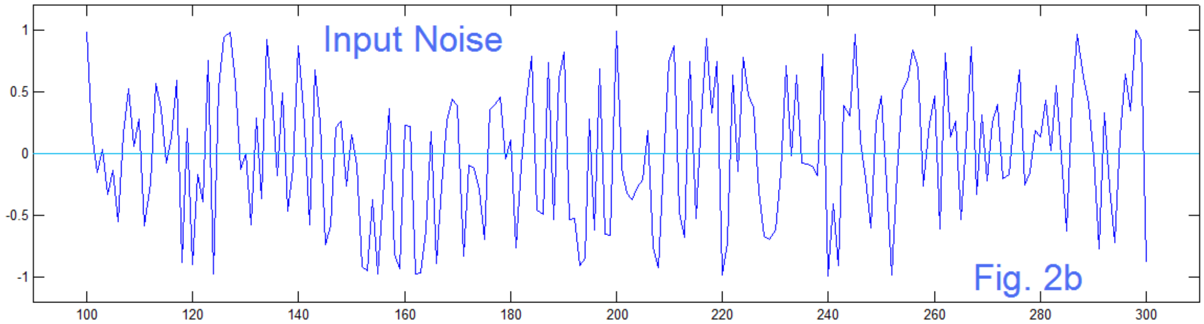


Fig. 1

In terms of engineering, and in fact a conventional notion of hearing range, something more like Fig. 2a is what we have as a simplified "model". Here we have a "toy hearing" that is



totally made up. It is made up with a goal of simplicity and as a <u>demonstration</u> (including a desire to make available sound examples that play fairly well on the Internet). So the hearing range of the toy is only three octaves (instead of seven) and the low end cutoff is set at 140 Hz with an upper limit of 1000 Hz. The filter here is a standard length-101 digital FIR filter [2]. In a real case, the low-frequency dip would likely be more like 70 Hz. Such a low frequency is already difficult to hear, and would further suffer over the Internet. The high-frequency dip would likely be more like 10 kHz, corresponding to an age-related normal loss (and not to a youthful 18 kHz). Also, we desire to keep the high frequency limit low enough for a reasonable sampling rate (5 kHz here) to keep file sizes small. <u>We emphasize it is a toy and we want a clear demonstration of the edge pitches.</u> Neither have we here examined a wide range of experimental parameters. The interested reader may wish to copy, modify, and run the code below, using Matlab if available, or perhaps the free alternative “Octave” that is sometimes used. This would also provide original sound files. The sound files linked here are .WMA files. There are only five different files. Playing (sequencing) the sound files using Matlab’s ***sound*** as in the code facilitates comparison. The input to the files is a length 14,000 random sequence intended for a 5000 Hz sampling rate. This gives us about 3 seconds of sound to listen to. The 14,000 samples are far too many to plot. Thus time sequence plots here, such as Fig. 2b and Fig. 2c, are truncated to just 200 samples, but are typical.



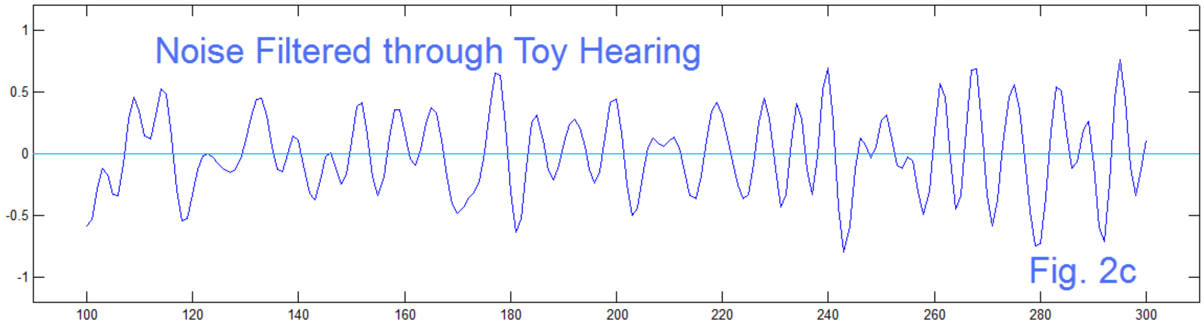


Fig. 2b shows 200 samples of the random input while Fig. 2c shows the same random signal as filtered by the "toy hearing" of Fig. 2a. The unfiltered signal would be regarded as being quite flat in frequency from 0 to 2500 Hz, and we see no striking patterns. The filtered version, in contrast, has significant hints of starting to look pitched. At this point the reader is invited to guess what the two waveforms of Fig. 2b and Fig. 2c might sound like. The answer is then:

Fig. 2b (random noise)

http://electronotes.netfirms.com/orignoise.WMA

Fig. 2c (toy hearing)

http://electronotes.netfirms.com/toy.WMA

where we keep in mind that the figures represent only 200 of the 14,000 samples we hear. The time index (100-300) corresponds to samples taken at 5000 Hz, so are 0.0002 seconds apart, and the full width of the plots is about 0.04 seconds. IF we were so bold as to count the rough "cycles" of Fig. 2c, we would likely get about 25. Thus the frequency would be 25/0.04 or 625 Hz. Compare this to the average of the two edges of the toy (140 + 1000)/2 = 570 Hz. Reasonable.

What you likely heard was not a tone but a "wind blowing around a corner" crude whistle. A bit eerie, but not uncomfortable or "jarring" as the random signal seems. Keep in mind that this toy is our **model** of day-by-day hearing and we are interested in what specific pitches we might, with careful listening, hear inside that band.

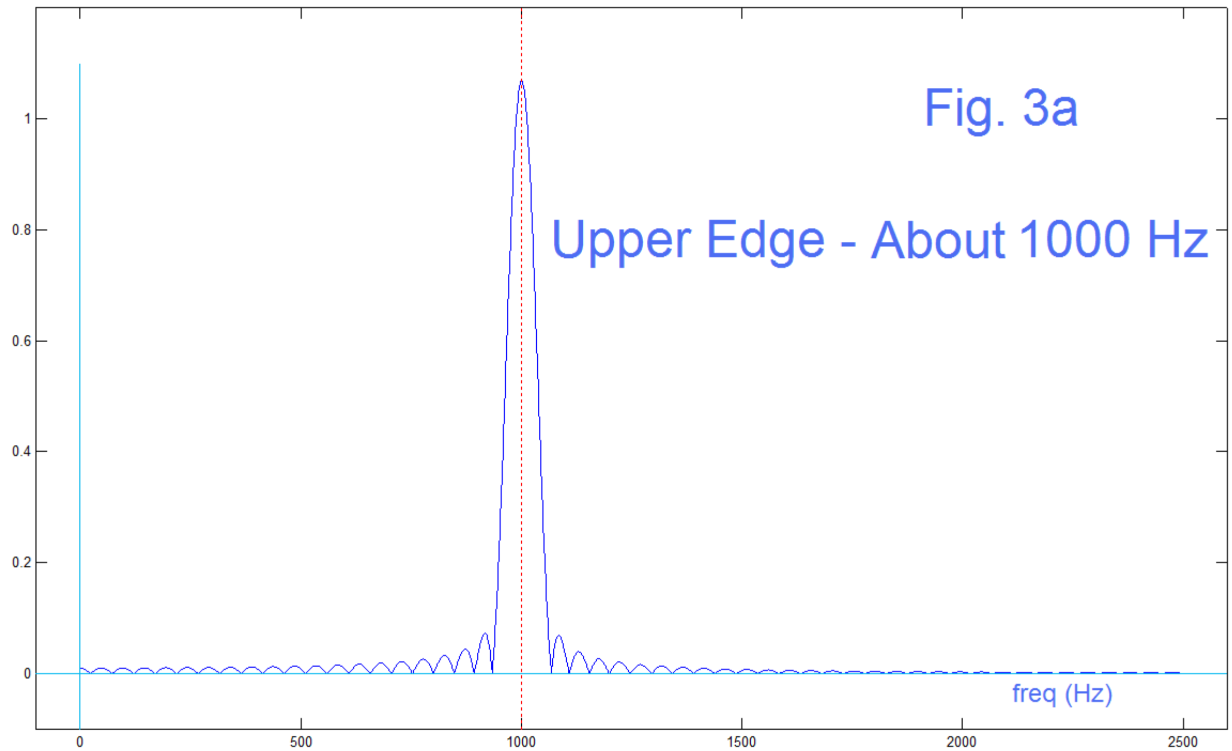
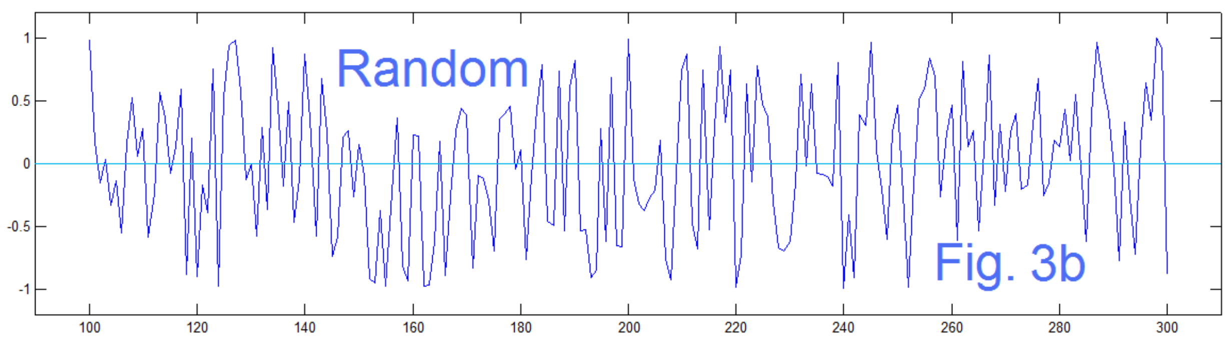
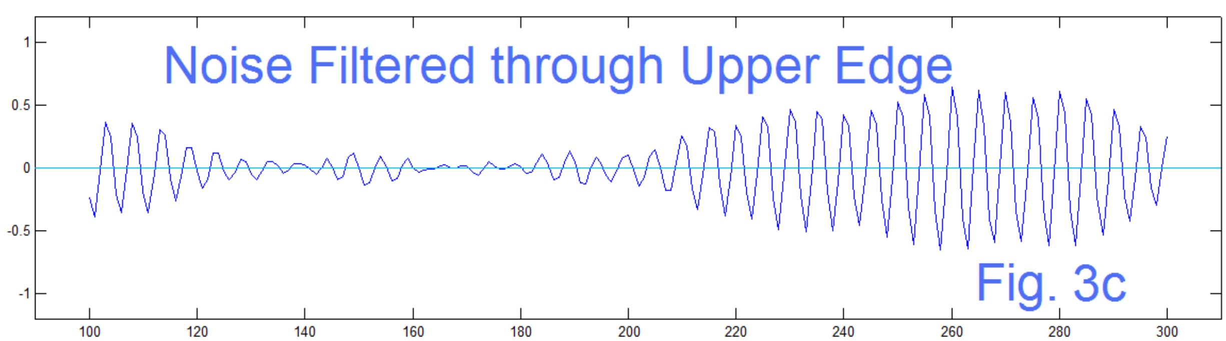


Fig. 3a
Upper Edge - About 1000 Hz
freq (Hz)


Random
Fig. 3b


Noise Filtered through Upper Edge
Fig. 3c

Here we will proceed to form a new filter for the random noise – a sharp band-pass about 1000 Hz: the upper edge of the toy. This is illustrated in Fig. 3a. This filter is fed with the original random noise (not the output of the toy). However this is a familiar example of "colored noise" in the music synthesis world. The random noise is taken to be "white" (a flat spectrum) so when filtered it is correspondingly called colored. Fig. 3c shows a result that shows a strong indication of a 1000 Hz pitch (40 cycles in 0.04 seconds is exactly 1000 Hz). Such filtered noise sequences are fully capable of carrying a melody. The large fluctuations in amplitude are expected statistically.

The following sound examples are relevant here:

Fig. 3b (same as Fig. 2b) (original noise)

http://electronotes.netfirms.com/orignoise.WMA

Fig. 3c (high-edge, 1000 Hz)

http://electronotes.netfirms.com/high.WMA

Fig. 2b (toy hearing)

http://electronotes.netfirms.com/toy.WMA

Here the initial playing of the random noise serves as a "palate cleanser" and is followed by the clear 1000 Hz colored noise. The task is then to see if this same 1000 Hz pitch is present in the toy, and I believe most listeners will clearly hear it as being present (along with a more general noisy rushing sound), particularly as "primed" by the isolated high edge file and/or by repeated playing. Working back and forth between 3c and 2b should be convincing.

This will illustrate for the reader the general concept of colored nose, and the more interesting notion of preferential hearing of a pitch at the edge. This has further interesting (although just inchoate) notions associated with classic (high frequency) tinnitus at the edge of a hearing decline [3].

Because there is interest in the so-called "Hum" (that some hear) [4] that is a low-frequency hum or buzz or rumble, our next test is to examine the lower edge down around 140 Hz in our toy example. This is **not** a clear result at all. But we shall proceed. Fig. 4a shows a sharp 140 Hz band-pass. This is driven by the random noise resulting in the output of Fig. 4c. This is encouraging as it appears as a graph. One can argue for just under 6 full cycles. Let's estimate 5 and 2/3 cycles. This would be (17/3)/0.04 = 142 Hz, so some result such as 140 Hz is reasonable. So, one might hope to hear a 140 Hz tone as clearly as we hear the 1000 Hz high tone, and hopefully in both the filtered noise and the toy (again with appropriate) priming. No such luck.

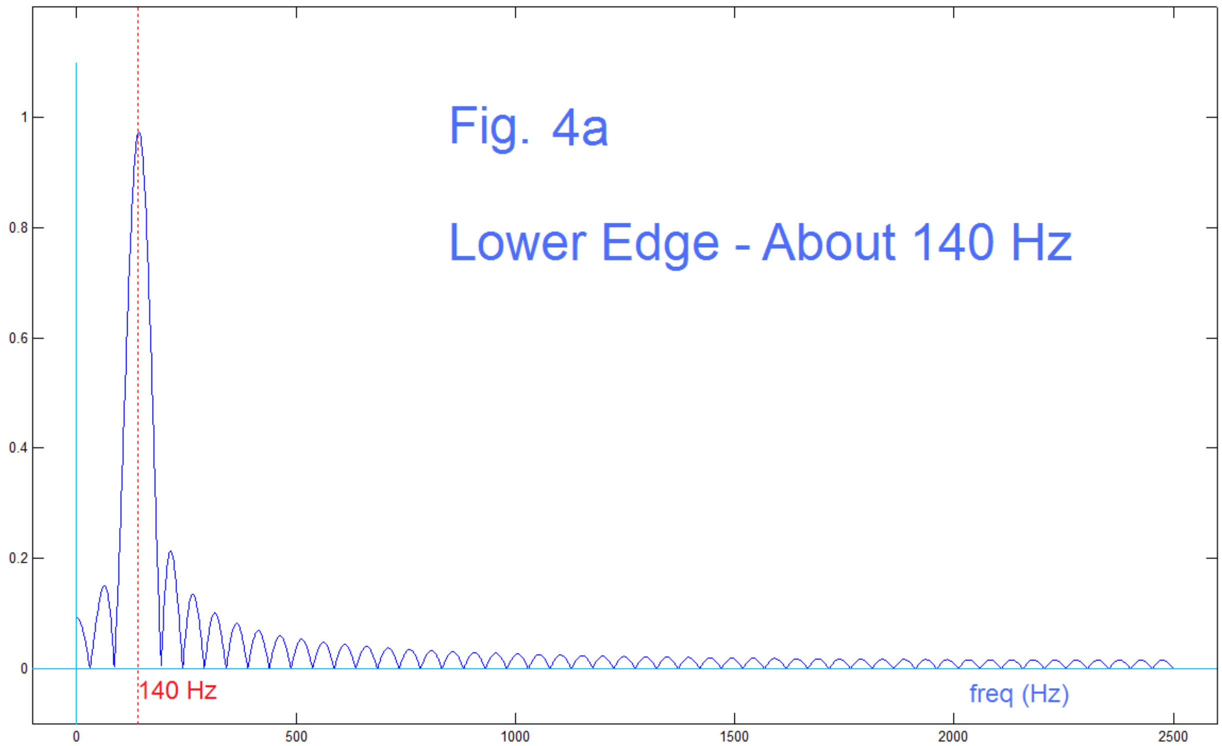
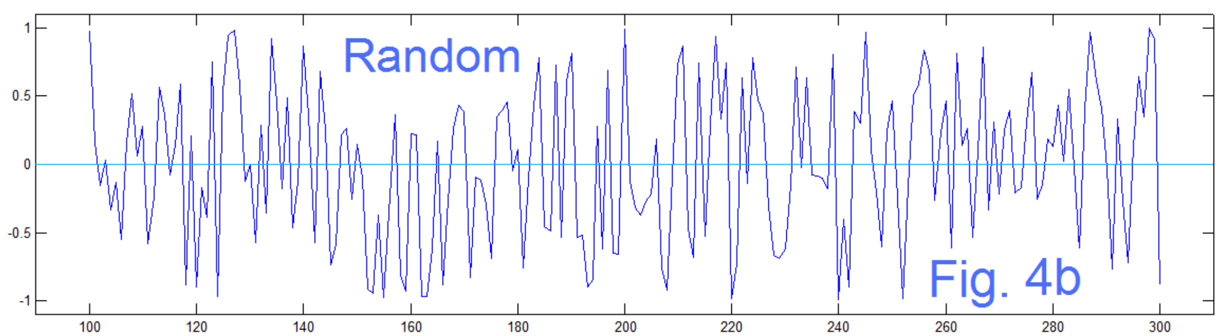
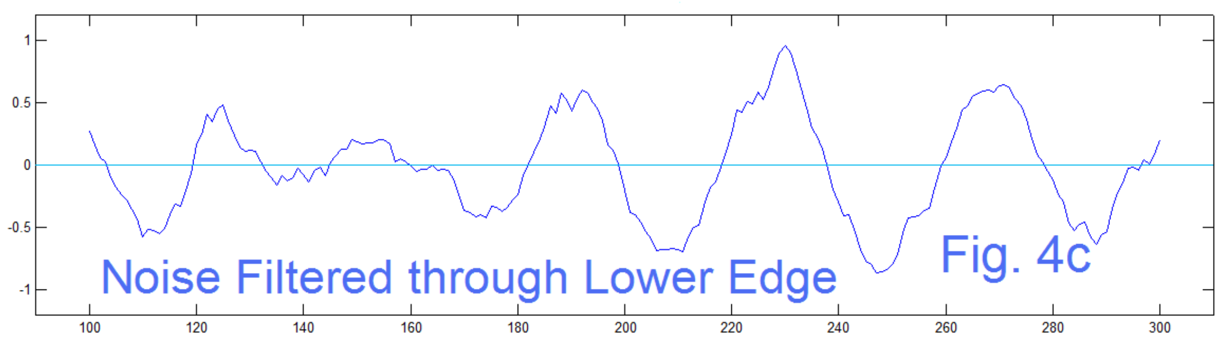


Fig. 4a
Lower Edge - About 140 Hz
140 Hz
freq (Hz)
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500


Random
Fig. 4b
1
0.5
0
-0.5
-1
100
120
140
160
180
200
220
240
260
280
300


Noise Filtered through Lower Edge
Fig. 4c
1
0.5
0
-0.5
-1
100
120
140
160
180
200
220
240
260
280
300

Here is a possible playing sequence:

Fig. 4b (same as Fig. 2b, etc.) (original noise)

http://electronotes.netfirms.com/orignoise.WMA

Fig. 4c (low-edge, 140 Hz)

http://electronotes.netfirms.com/low.WMA

Listen to this first. Then start a simultaneous online tone generator set to 140 Hz. Make it loud enough that you can clearly hear the 140 Hz tone, and get used to the mix. Now turn down the tone generator so that you can barely hear it. Toggle the 140 Hz completely off and on and listen for it in the low edge when the generator is off. I hear very brief but basically convincing spurts (perhaps three per second) of 140 Hz. There is a lot more going on as well.

Fig. 2b (toy hearing)

http://electronotes.netfirms.com/toy.WMA

Try the green instructions now with the toy. I don't hear any 140 Hz. Thus the notion of a clear edge pitch at such a low frequency, going down, is not in evidence.

A "control" here is to see if a pitch in the middle of the band can be heard in the toy. We choose this rather arbitrarily as 440 Hz (the pitch an orchestra tunes to). The filter here is shown in Fig. 5a. There should be little doubt that we expect to hear a colored noise at 440 Hz coming out of the band-pass, as seen in Fig. 5c where we see 18 cycles and a suspected pitch of 18/0.04 = 450 Hz, close enough to 440 Hz. Here is the playlist:

Fig. 5b (same as Fig. 2b, etc.) (original noise)

http://electronotes.netfirms.com/orignoise.WMA

Fig. 5c (440 Hz)

http://electronotes.netfirms.com/mid440.WMA

Fig. 2b (toy hearing)

http://electronotes.netfirms.com/toy.WMA

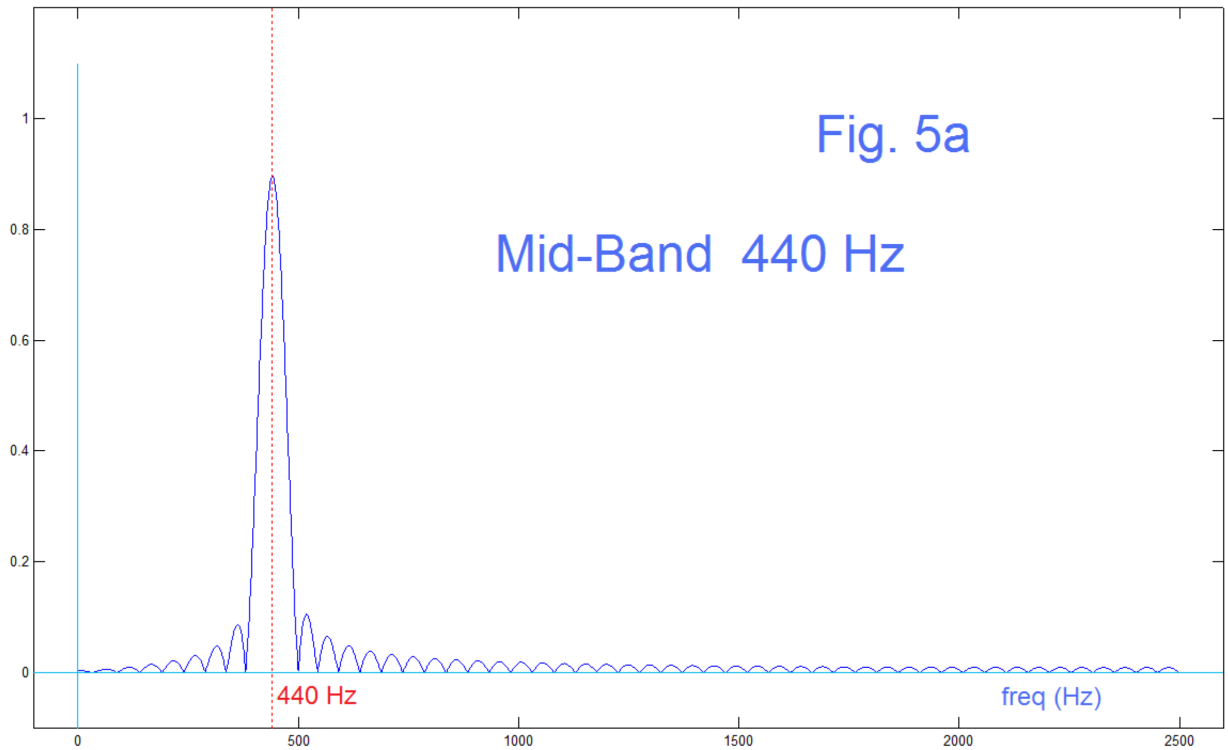
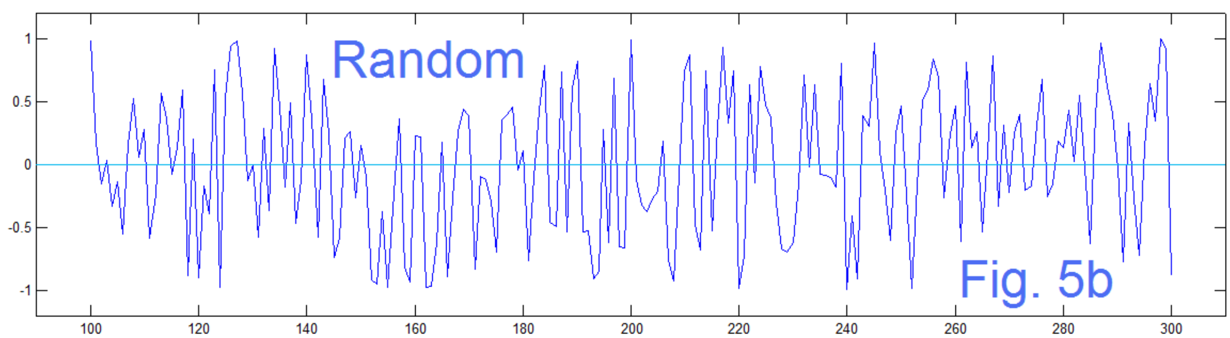
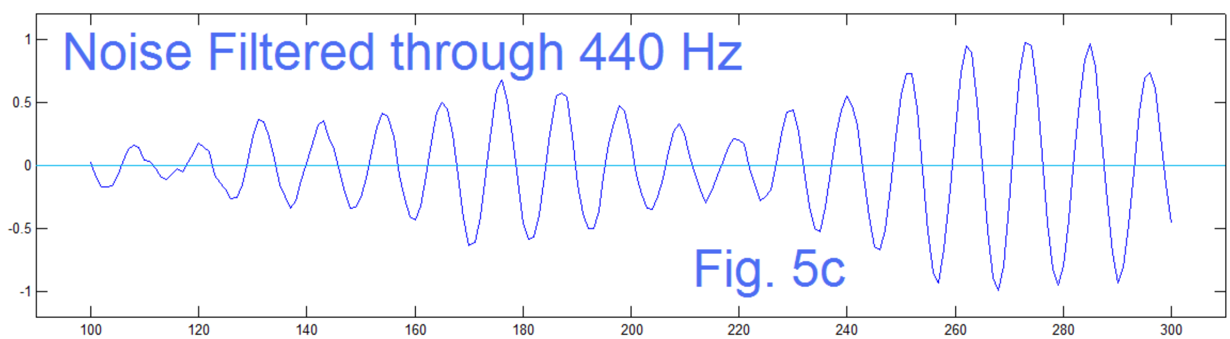


Fig. 5a
Mid-Band 440 Hz
440 Hz
freq (Hz)


Random
Fig. 5b


Noise Filtered through 440 Hz
Fig. 5c

As suggested, we do hear the 440 Hz colored noise (Fig. 5c) without difficultly. But the question of interest is whether or not we hear 440 Hz in the toy hearing and/or if it can be coaxed out by a sinusoidal comparison tone. The answers to both appears to be no. This leads to thoughts about what it means to be on the edges as compared to being in the middle. An edge has significant energy on one side only, and edges are different from mid-band tones which have energy on both sides. So while we likely do get some stimulus from 440 Hz in the toy, we have no call to favor 440 Hz as compared to 441 Hz or to 199 Hz or to 555 Hz, for example. Except at the edges, everybody is equal.

HERE US A FULL PLAYLIST FOR THE FIVE EXAMPLES

ORIGINAL NOISE: http://electronotes.netfirms.com/orignoise.WMA

LOW EDGE: http://electronotes.netfirms.com/low.WMA
MIDDLE (440 Hz): http://electronotes.netfirms.com/mid440.WMA
HIGH EDGE: http://electronotes.net firms.com/high.WMA

TOY HEARING: http://electronotes.netfirms.com/toy.WMA

DISCUSSION

The original idea prompting this study and report was that the notion of an edge pitch with high-frequency hearing loss (offered as a possible explanation of high-frequency tinnitus) might be proposed in a mirror-image to be considered in relation to Hum and a low-frequency limit. That is, much as some research suggests a tinnitus frequency (perhaps 5000 Hz) relating to a high-frequency limit (age-related loss), so might a Hum frequency be related to hearing limits on the low-frequency side (say below 100 Hz). In my case, I hear a Hum at 64 Hz and have a very rapid roll-off below that (by 55-60 Hz). It would be a lovely symmetry if true.

Here we have offered a methodology and some audio results which others can attempt to verify and/or expand on. That's the story so far.

The clear and expected results are for the sharp band-passed noise at 440 Hz and at 1000 Hz, both of which are well-understood (many years) colored noises. We further understand the 1000 Hz heard fairly easily in the toy-hearing as an edge pitch [5]. Further still, we understand the lack of any substantial tracking of a 440 Hz pitch in the toy as a necessary consequence of having an edge as being important. If we had heard the 440 Hz in the toy, that would have been unexpected.

The results on the low-frequency edge are not so dramatic. Originally, I tried this at about 70 Hz but that was too much strain on computer audio, not to mention the extreme of low-frequency hearing. Moving the edge up to 100 and finally to 140 Hz means that the 140 Hz component of the sharp band-pass could just be noted when alternated with a 140 Hz pure tone. (Note that even though there is a strong peak in Fig. 4a at 140 Hz, from Fig. 1, the actual hearing is down by something like 20 db). Given this minimal detection in the sharp band-pass, it is no real surprise that no 140 Hz could be heard in the toy hearing. No attempt to simulate the actual Hum is intended.

REFERENCES

[1] B. Hutchins, "Why No Range-Switch with Hearing?", Electronotes Application Note No. 428 July 10, 2016 http://electronotes.netfirms.com/AN428.pdf

[2] Digital Signal Processing Notes Part 2, ELECTRONOTES 198 Vol. 20 June 2001 http://electronotes.netfirms.com/EN198.pdf

[3] M. Sereda et al "Relationship between tinnitus pitch and edge of hearing loss in individuals with a narrow tinnitus bandwidth", Int J Audiol. 2015 Apr; 54(4): 249–256. Published online 2014 Dec 3. doi: 10.3109/14992027.2014.979373 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4438350/

[4] B. Hutchins, "Current View of My View of 'The Hum' ", Electronotes Webnote 40, 5/6/2016 http://electronotes.netfirms.com/ENWN40.pdf

[5] Houtsma, A.J.M., Chapter 8 Pitch Perception, pg 283 (1995) http://web.mit.edu/hst.723/www/ThemePapers/Pitch/Houtsma95.pdf

PROGRAM

```
%edge2.m

%
% *********************************************************************
%
%    BAND
%
h=firls(101,(1/2500)*[0 130 150 950 1050 2500],[0 0 1 1 0 0]);
%  band 140 Hz - 1000 Hz  "toy hearing"
figure(1)  % Freq Response
plot([0:1:2499],abs(freqz(h,1,2500)))
hold on
plot([-100 2600], [0 0],'c')
plot([0 0],[ -.1 1.1],'c')
plot([140 140],[-.1 1.5],'r:')
plot([1000 1000],[-.1 1.5],'r:')
axis ([-100 2600 -0.1 1.2])
hold off
title('Toy Hearing Response')
%
r=2*(rand(1,14000)-0.5);                % Noise   length 14000 fw=5000 3 sec.
rf=filter(h,1,r);
rftoy=rf;
% Store toy hearing
%
disp('ORIGINAL AND TOY')
disp('Original Unfiltered Noise')
%wavwrite(r,5000,'c:\en-site\orignoise.wav')
sound(r,5000)                           % Original noise
pause
%
disp('Toy Hearing')
wavwrite(rftoy,5000,'c:\en-site\toy.wav')
sound(rftoy,5000)                          %
pause
%
% plot of samples 100-300 of 15000
figure(2)
subplot(211)
plot([100:300],r(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.2 1.2])
title('input noise, 100-300')
%
subplot(212)
plot([100:300],rf(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.2 1.2])
title('Toy hearing, 100-300')
```

```
%
%*****************************************************************
%
%    Low Edge
%
h=firls(101,(1/2500)*[0 120 130 150 160 2500],[0 0 1.8 1.8 0 0]);
%  band 130 Hz - 150 Hz  "low edge"
figure(3) % Freq response
plot([0:1:2499],abs(freqz(h,1,2500)))
hold on
plot([-100 2600], [0 0],'c')
plot([0 0],[ -.1 1.1],'c')
plot([140 140],[-.1 1.5],'r:')
axis ([-100 2600 -0.1 1.2])
hold off
title('Low Response')
%
rf=filter(h,1,r);
disp('************************')
disp('LOW EDGE')
disp('Original Noise')
sound(r,5000)                           %Original noise
pause
wavwrite(2*rf,5000,'c:\en-site\low.wav')
disp('Filtered as low edge')
sound(2*rf,5000)                          %
pause
disp('Toy Hearing')
sound(rftoy,5000)                          %
pause
% plot of samples 100-300 of 15000
figure(4)
subplot(211)
plot([100:300],r(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.1 1.1])
title('input noise, 100-300')
%
subplot(212)
plot([100:300],5*rf(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.2 1.2])
title('Low edge, 100-300')

%
%
% *******************************************************
%
%    High Edge
%
h=firls(101,(1/2500)*[0  950 975 1025 1050 2500],[0 0 1 1 0 0]);
%  band 130 Hz - 150 Hz  "high edge"
figure(5)    % Freq Response
plot([0:1:2499],abs(freqz(h,1,2500)))
hold on
plot([-100 2600], [0 0],'c')
```

```
plot([0 0],[ -.1 1.1],'c')
plot([1000 1000],[-0.1 1.5],'r:')
axis ([-100 2600 -0.1 1.2])
hold off
title('High')
%
rf=filter(h,1,r);
disp('*******************************')
disp(' HIGH EDGE')
disp('Original Noise')
sound(r,5000)                           %Original noise
pause
wavwrite(rf,5000,'c:\en-site\high.wav')
disp('Filtered as High Edge')
sound(rf,5000)                          %
pause
disp('Toy Hearing')
sound(rftoy,5000)                          %
pause
% plot of samples 100-300 of 15000
figure(6)
subplot(211)
plot([100:300],r(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.2 1.2])
title('input noise, 100-300')
%
subplot(212)
plot([100:300],5*rf(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.2 1.2])
title('High edge, 100-300')

%
%
%
% *******************************************************
%
%    440 Hz
%
h=firls(101,(1/2500)*[0  400 430 450 480 2500],[0 0 1 1 0 0]);
%  440 Hz
figure(7)
plot([0:1:2499],abs(freqz(h,1,2500)))
hold on
plot([-100 2600], [0 0],'c')
plot([0 0],[ -.1 1.1],'c')
plot([440 440],[-0.1 1.5],'r:')
axis ([-100 2600 -0.1 1.2])
hold off
title('440')
%
rf=filter(h,1,r);
%
```

```
disp('********************************')
disp('COMPARISON 440 Hz')
disp('Original Noise')
sound(r,5000)                           %Original noise
pause
%
wavwrite(rf,5000,'c:\en-site\mid440.wav')
disp('Filtered 440')
sound(rf,5000)
pause
%
disp('Toy Hearing')
sound(rftoy,5000)                          %
% pause   omit last pause
%
% plot of samples 100-300 of 15000
figure(8)
subplot(211)
plot([100:300],r(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.2 1.2])
title('input noise, 100-300')
%
subplot(212)
plot([100:300],5*rf(100:300))
hold on
plot([90 310],[0 0],'c')
plot([0 0],[-1.1 1.1],'c')
hold off
axis([90 310 -1.2 1.2])
title('440')
```