ELECTRONOTES

WEBNOTE 38 4/11/2016

ENWN-38

NOTCHING TO TRY TO DISPLAY "THE HUM"

Here we continue a discussion of "The Hum" that was the subject of two previous webnotes:

[1] ENWN-31 2/13/2016 "Oh-Hum" http://electronotes.netfirms.com/ENWN31.pdf

[2] ENWN-37 4/08/2016 "More on The Hum" http://electronotes.netfirms.com/ENWN37.pdf

Here our goal is to continue with the investigation of displaying low-frequency audio with a storage scope to see if anything suggesting the Hum has a physical correlate that is traditional audio. In the second webnote [2], we noted that it was difficult to examine this low-frequency range because of electrical and possibly acoustic interference due to the AC supply lines. We noted that we had a significant amount of 60 Hz signal and apparently an even larger amount of 120 Hz. These amounts varied with time. The plots obtained with a scope camera or storage scope also showed an extremely variable component (relatively small) in the 10-20 Hz range. A goal at that point was to attempt to get rid of the AC line interference by "Notching" it out, if possible. Here we will tell you about the filter in order to say exactly what I tried, and to tell you enough about the design so that you could reproduce it (and/or modify it for 50 Hz if that's your frequency). NOTE WELL: the circuit diagram in Fig. 1 is not as bad as it looks. The design was "simplified" (by using more parts) to make it easier to experiment with. Parts for the circuit are only about $8. It also needs support equipment (standard lab stuff) like breadboards, power supplies and scopes; and function generators, frequency counters, etc. may be useful.

ABOUT NOTCH FILTERING

Notch filtering begins with the idea that there are usually one or more frequencies that we don't want so we propose to block them while passing everything else. Quite impossible to do. We will settle for nulling out the offending frequencies while settling

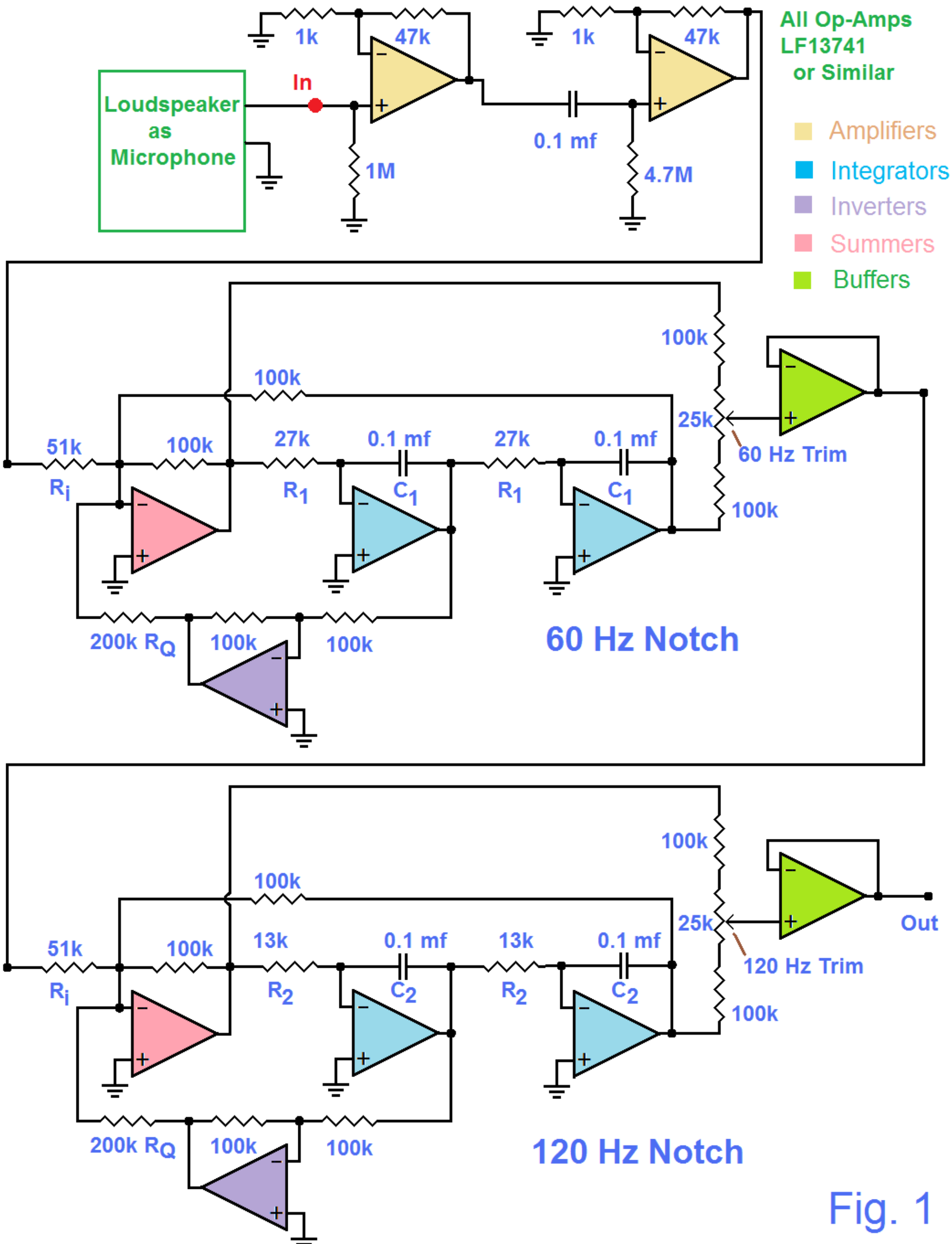

Fig. 1

for some losses of possibly desired material. It is the case that a version of the "Uncertainty Principle" (a Fourier transform property – not just quantum mechanics) is appropriate here: when we speak of a particular frequency it is not just a single cycle or even a dozen cycles, but a sinusoidal waveform for ALL time. The notch filter, even when optimized, fights off segments. It can't completely block everything we might suppose. In the case of stray pickups, the notch filter is expected to HELP.

THE DESIGN

There are many ways to implement notch filters [3-5]. The most generally useful of these are probably those which use only a single op-amp for each notch. The circuit of Fig. 1 has two op-amps at the top (yellow) that amplify the input signal. The ten op-amps below form two notch filters using the "state-variable" approach (three to five op-amps each, five here). If I had used a single op-amp circuit for the notch filters, there would have been only four op-amps total in Fig. 1. The upside to using five rather than just one is that the parameters of the response are dependent, each individually, on only one circuit element value. With one op-amp circuits, if you needed to change the Q, for example, you generally have to change the values of multiple elements. Since op-amps are cheap (less than 50 cents) and because I am only building one set, we opt for simplicity during use.

Here the "backbone" is the traditional two integrators (blue) with a feedback summer (pink) in a loop. The inverter (purple) simplifies the setting of the Q. This places a pair of poles NEAR the notch frequency. We are not overly concerned with setting the poles exactly, as the poles do not determine the notch frequency. Rather the poles support the response immediately adjacent to the null mandated by the zeros. It is the setting of the zero, as trimmed to the buffer (green) that matters.

The notch is the summation of the high-pass (output of summer) and the low-pass (rightmost of the integrators), and this mix ((ideally equal) sets the notch frequency. If we were concerned with having the two sides of equal height, the placement of the

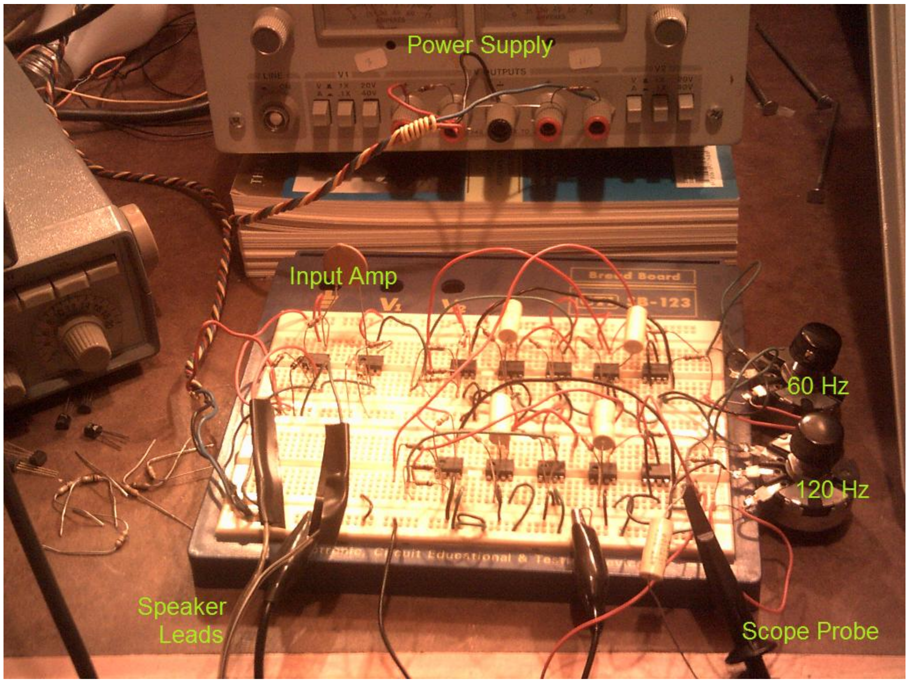

Fig. 2

poles at the frequency of the zeros would be important. Here we just require the poles to keep the notch sharp. The pot trims the null rather exactly. Fig. 2 is a photo of the bread-boarded amplifier/filter.

The following equations may be useful. The pole frequency is:

$$f_p = 1/2\pi RC$$

where R and C are the integrator components (R_1 and C_1 for the 60 Hz notch, and R_2 and C_2 for the 120 Hz notch). It is the RC product that matters. If you live in a 50 Hz country, simple increases of resistors for R_1 (for both integrators) and for R_2 (for both integrators) should suffice. The "Q" of the circuit is $Q=R_Q/100k$. Q here was set to 2 (R_Q=200k), which is fairly low. (The problem getting Q too high is that the circuit can "ring" and produce exactly what it is trying to reject.) The gain of the circuit from input to notch output is unity. Nominally gain = $(1/2)(100k/R_i)$. Hence R_i = 51k. The loss of 1/2 is due to the passive mixer that forms the notch.

OPERATION

This turned out well. It circuit worked the first time! I have probably bread-boarded or circuit-boarded dozens of these myself and trouble-shot hundreds for students in lab. This is not to suggest that the application was trouble-free.

I was thinking that I might just splice in the filters and tune them (adjust the two pots) by watching the AC line noise drop on the scope. In fact, the ambient AC noise was not large enough, or stable enough, to do this. Remember that the poles were only roughly set by the 5% tolerance components. The trim of the zeros is the 25k pot vs the 100k added to each side. Both pots (nominally centered) eventually ended up well off center.

So the task was then to get out a function generator and a frequency counter. This was input to just the notch filters – instead of using the amplifiers. (The function generator output is large). The frequency counter could count for 10 seconds so as to give a pretty good setting to 60 Hz and to 120 Hz, far better than the function generator dial. Thus you set the function generator to 60 Hz and adjust the upper trim for a very good null. Then you move the function generator up, and the output of the filter pair comes back up. Set the function generator to 120 Hz and null out the lower trimmer. DONE.

Finally, you are in a position to attach the speaker and amplifiers (or other sources) back up to the input of the notch filters. We are about to see what the "residual" to the power-line noise is. Exciting! Well- NO – it's still a mess. Fig. 3 and Fig. 4 compare the unfiltered case (three examples) to the filtered case (three examples of that).

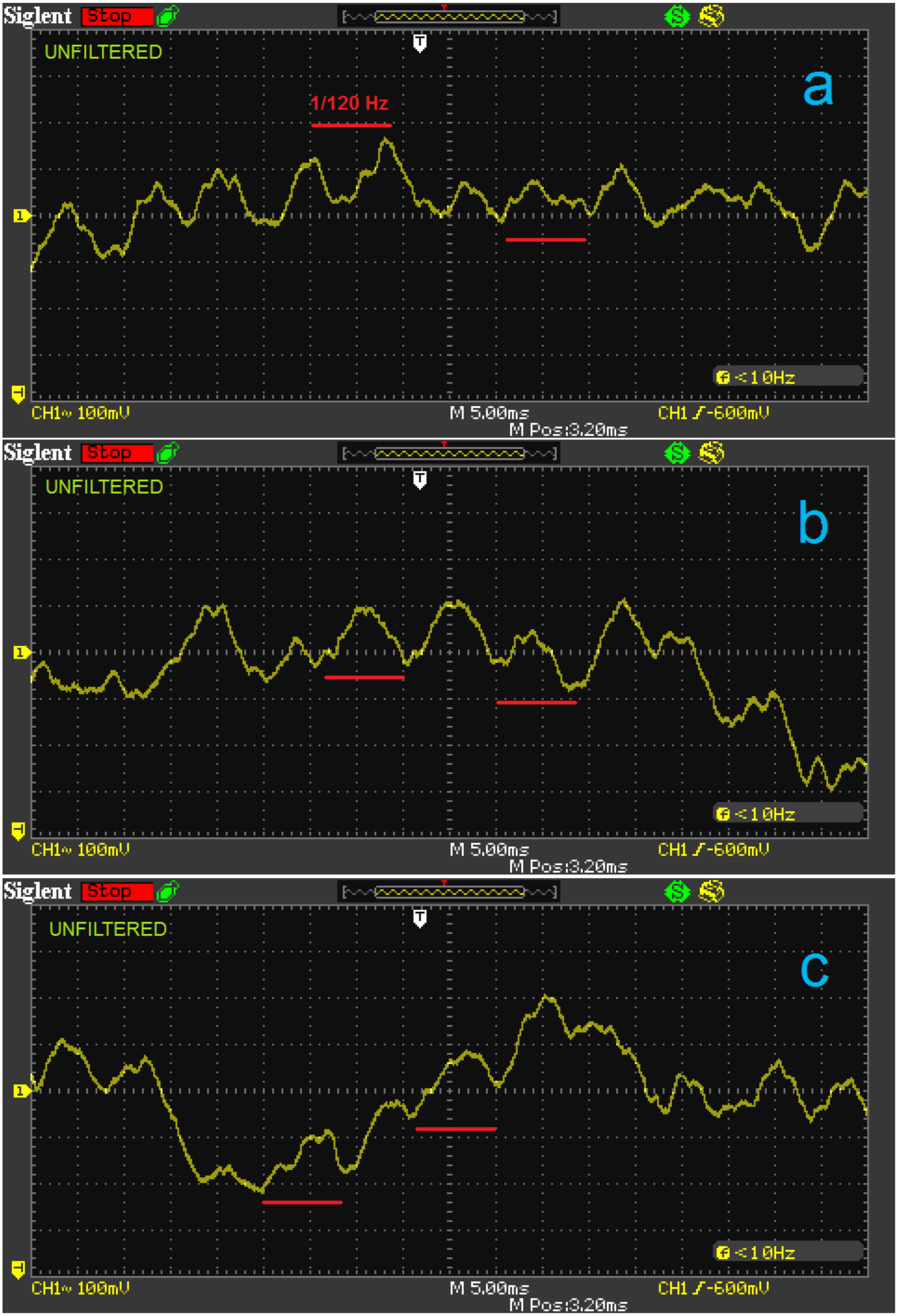
Siglent
Stop
UNFILTERED
1/120 Hz
a
CH1~ 100mV
M 5.00ms
M Pos:3.20ms
CH1 -600mV
<10Hz
Siglent
Stop
UNFILTERED
b
CH1~ 100mV
M 5.00ms
M Pos:3.20ms
CH1 -600mV
<10Hz
Siglent
Stop
UNFILTERED
c
CH1~ 100mV
M 5.00ms
M Pos:3.20ms
CH1 -600mV
<10Hz

Fig. 3

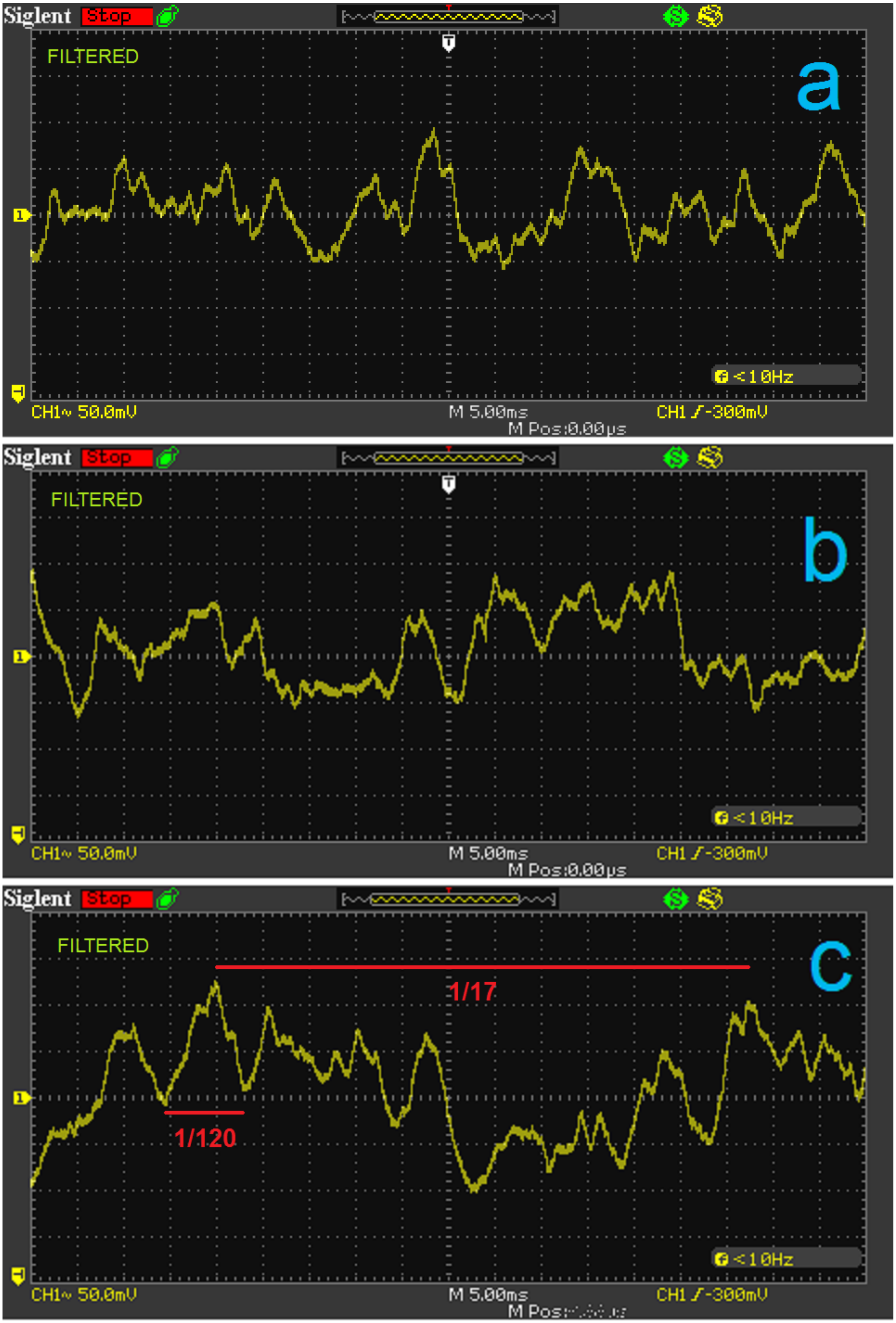
Siglent Stop
FILTERED
a
CH1~ 50.0mV
M 5.00ms
M Pos:0.00μs
CH1 -300mV
<10Hz
Siglent Stop
FILTERED
b
CH1~ 50.0mV
M 5.00ms
M Pos:0.00μs
CH1 -300mV
<10Hz
Siglent Stop
FILTERED
c
1/17
1/120
CH1~ 50.0mV
M 5.00ms
CH1 -300mV
<10Hz

Fig. 4

We emphasize here that the displays in Fig. 3 and Fig. 4 are just barely representative, and not definitive of any finding. (On many occasions we have worried about misleading the reader by choosing a particular plot of something that is very noisy if not completely random. Here we have chosen consecutive plots as they came along.) Two generalities were found. First, the filtered examples are lower amplitude, as one would expect by taking out known components. (The notches were otherwise unity gain). About half the amplitude is gone due to the filtering. Secondly, the filtered cases have fewer examples of what we might want to attribute to 120 Hz (red bars). We noted that the power line noise was principally 120 Hz (second harmonic).

Does anything remain? Sure, but it's very difficult to characterize. A very tentative possible exception is the low frequency as appears in Fig. 4c which would be about 17 Hz, roughly consistent with the findings in the unfiltered examples [2] (15 Hz, 13 Hz). The observations are not consistent enough to speculate. In any case, the frequencies are too low to be audible. (Remember that the low-frequency response rolls down to insignificance by 15 Hz. If you think you can hear 15 Hz, think again. You are hearing clicks at a repetition rate of 15 Hz.)

Suppose there is something acoustic at low frequencies – in my basement. What could it be? It occurred to me it might be a natural resonance stirred up occasionally by random fluctuations. Few of us live in perfectly rectangular boxes, but there are plenty of programs on line for resonant modes of rooms. My lab space is very very roughly 40 feet by 30 feet by 8.5 feet. One calculator [6] gives modes of 13.8 Hz (the c/2L mode [7]), 15.2 Hz, 16.35 Hz, 18.5 Hz, etc. All these are in the right ballpark. So, to test this, we have only to stomp our foot and watch a decay. Well, I tried that and it comes out closer to 60 Hz (exponentially decaying sinewave).

AT THIS POINT

As a result of experiments here and a lack of positive reported results (recordings or displays) there is no evidence that the Hum is an acoustical event in the sense of a vibration in air.

For reasons outlined in the referenced webnotes [1, 2] explanations in terms of signals (acoustic, or electromagnetic) are implausible.

An explanation in terms of natural fluctuations of muscles and nerves resulting in reports to the brain in areas normally interpreted as external audio seem most likely.

REFERENCES

[1] "Oh-Hum" , Electronotes Webnote ENWN-31, 2/13/2016, http://electronotes.netfirms.com/ENWN31.pdf

[2] "More on The Hum" Electronotes Webnote ENWN-37 4/08/2016 http://electronotes.netfirms.com/ENWN37.pdf

[3] "Notch Filtering – Some Notes", Electronotes Application Note No. 413, July 30, 2014 http://electronotes.netfirms.com/AN413.pdf

[4] Here (copied from AM-413 above) is a guide to finding some of the many presentations we have done on notch filtering over the years.

[4a] Analog Signal Processing, Section 4-2 (notch filtering), ***Electronotes***, Vol. 19, No. 193, March 2000, pp 6-10. http://electronotes.netfirms.com/EN193.pdf

[4b] Analog Signal Processing , Chapter 5, pp 9-10 of ***Electronotes***, Vol. 20, No 194, April 2000 (a bit more on a general single op-amp M.F.I.G. approach). http://electronotes.netfirms.com/EN194.pdf

[4c] A whole series of Electronotes Application Notes were published in 1980

AN-183 "Elements of Notch Filter Design", July 25, 1980

AN-184 "Selection of Notch and Bandstop Responses", August 5, 1980

AN-185 "Notch Filter Using Simulated Inductor", August 15, 1980

AN-186 "State-Variable Input-Notch Structure", August 25, 1980

AN-187 "State-Variable Output-Notch Structure", September 4, 1980

AN-188 "The Bootstrapped Twin-T Notch", September 11, 1980

AN-189 "Notch Filter by Bandpass Subtraction," September 18

AN-209 "Limited Depth Notch Filtering", March 11, 1981

[5] Analog Signal Processing , Chapter 6, Section 6-2. pp 20-24 ***Electronotes***, Vol. 20, No 194, April 2000 (analysis for state-variable) http://electronotes.netfirms.com/EN194.pdf

[6] http://www.bobgolds.com/Mode/RoomModes.htm

[7] the eigenmode frequencies are: $f = \left(\frac{c}{2}\right)\sqrt{(\frac{n_L}{L})^2 + (\frac{n_W}{W})^2 + (\frac{n_H}{H})^2}$