ELECTRONOTES

WEBNOTE 36 4/7/2016

ENWN-36

ENGINEERING "LICENSE"

-by Bernie Hutchins, April 2016

Are you an Electrical Engineer? How would you know? How would you prove it?

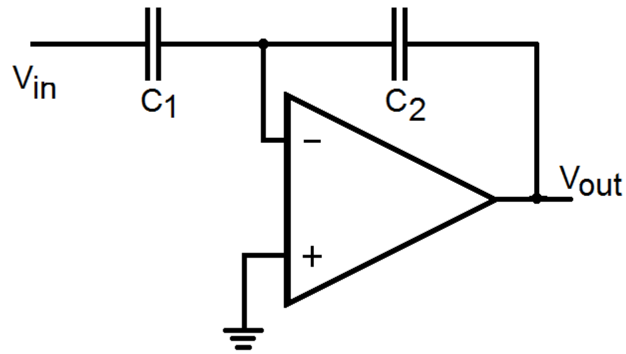
Happily I think engineers tend to describe a person's professional qualifications in terms of what he/she does and how well he/she does it. Or perhaps in terms of an official job title upon hiring. Or perhaps by education, if recent. But mostly by actions.

The issue of a "license" seldom comes up except perhaps in Civil Engineering. My experience with a license in EE is limited: one student. The student, Mack, needed to get a license for some specific job. He showed up at my door a year or so after graduation, and I was glad to see him. He was reviewing for the exam, and had a review or prep book as I recall. In that endeavor, he was not a "happy camper". I think he had sorted out three problems from the book that involved subjects I had taught him. Logical enough.

The problem was that I could not answer the important question: "Should he attempt to answer with the <u>right</u> answer or the one he surmised was the one that would be graded as being correct ! This is not a new dilemma for a student facing an exam. In the university, if you gave the right answer and it is graded as incorrect because the examiner is wrong, you at least have the chance to defend your choice. What would happen with the professional exam? I never learned whether or not a person taking a license exam had the opportunity to object. I would hope so – but that's only a hope. Does anyone know?

Of the three problems Mack had singled out, I only remember one, which is paraphrased in the figure on the next page. You were supposed to relate V_{out} to V_{in}. I would hope that the reaction of the candidate would be to ask a two-part question: is the op-amp to be considered real (in which case the answer is trivial), and if it is not real, why is it on a practical exam!

So what is the choice of answers? Well if the two impedances were resistors instead of capacitors, we would recognize that we had a standard op-amp inverter and we would have $V_{out}/V_{in} = -R_2/R_1$. A refinement in that case would be to use a real op-amp model, and we would have, eventually, a low-pass filter.



In the case of the capacitors, Mack was supposing (as did I) that they had in mind that the candidate should answer $V_{out}/V_{in} = -C_1/C_2$, recognizing that the impedance of the capacitors goes as the reciprocal of the capacitance. [Indeed it is interesting that the frequency dependence cancels out.] Likewise, we could refine this with an op-amp model.

But something more fundamental about a real op-amp comes in first. I asked Mack what the correct answer really was. "It ramps", he volunteered, "like the way we measured input bias current." I was immensely pleased with his answer. "And eventually it clips at one supply rail or the other," I added. A bias current (perhaps small or even tiny) flows into or out of the (-) terminal. There is no DC path for this, so it linearly charges the capacitors. A worthless circuit.

[In a variation, we do use this as a "shelving equalizer" by having each impedance a parallel combination of a capacitor and a resistor. This was presented in App Note AN-194, attached below. Possibly this AN is our most frequently referenced note outside the electronic music community itself.]

So I was not impressed with the licensing possibility. Anyway, the category of EE is too broad and specialized now days. It's not like a real-estate agent or even a physician. An expert on Fourier transform could well score very poorly in power systems or semiconductor physics, as just an example. Meaningless? Who was the redoubtable editor of ***Electronic Design*** (George somebody) who held the very idea of an engineering license in total disdain?

Anyone have experience and/or opinions on this issue?

THE IMPORTANCE OF THE RIGHT ANSWER

Above I have discussed an example of examination where questions can be faulty or not correctly stated. Often, I suppose, some exams are hastily written. This is not to say that many instructors do not make substantial effort to make the exams error free and clearly stated. None the less there is some possibility of error, or a student may misunderstand the details. In such a case, the final answer will likely be wrong. At least in my experience, it was possible to have a totally wrong answer and receive full credit (taking off half a point and having it round back up at the end). The test was for knowledge and not for performing error-free under pressure. On the other hand, you were expected to demonstrate adequate command of the subject matter. If you misinterpreted or made an error which oversimplified the problem, that would not do.

While instructors easily tire of grading complaints relating to insufficient credit awarded (in the student's opinion), there was never a reluctance to address the possibility that the instructor was in error, mostly with regard to material presented in lecture.

I have previously told stories about this issue " Lasting Impressions - and Other Memories."

http://electronotes.netfirms.com/ENWN21.pdf

For example, Professor X had office hours and students contended that they were right because they had been told something. "Who told you that?," he asked. "Bernie did," they replied. "Well go tell him he's wrong." What a delight. I have no recollection of the issue or who was right, but it was typical of the "banter" that almost always led all, students and instructors, to a better understanding.

Taking this around the circle back to the "exams-man-ship" issue of answering a question so as to get the best grade, we had another professor, Professor Y, who had, during a review session, told the students something. We also had a very good (perhaps best ever) TA who volunteered to give a weekend review session. During that review, the TA said something different. When told that Professor Y had a different view, the TA explained why he (the TA) was right. I wasn't there, but the TA was clearly convincing. One student, concerned about the discrepancy asked, "Are you or Professor Y going to grade the exam?" The TA replied that the student "could not be missing the point more", the point being to get the right answer.

It is a point little appreciated in the traditional view of a university how much of what is learned is the result of a "scrum" involving students, instructors, and professors where true and lasting understanding is achieved. By the time the students become juniors and seniors, they need to have found themselves welcomed to question. Similarly the purpose of the labs is to form a unique "I did that MYSELF and remember [tactilely perhaps] the result": lasting memory. Mack did the experiment of connecting a capacitor to the (+) input of an op-amp follower and measuring dv/dt with a watch and then the bias current was I = C dv/dt.

Below – Reprint of AN-191

ELECTRONOTES

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APPLICATION NOTE NO. 194*

November 4, 1980

SIMPLE SHELVING EQUALIZER

The circuit of Fig. 1 is about as simple as a circuit can get consisting of an op-amp and two resistors and two capacitors. The circuit has one gain at low frequencies, and a different gain at high frequencies. Inbetween, the gain changes smoothly from one to the other. Since the gain is level except in the transition region, the flat regions look something like shelves, and you can push something up to a higher shelf, or down to a lower shelf. The levels of the shelves can be chosen for whatever values you need. Some typical examples are sketched in Fig. 2.

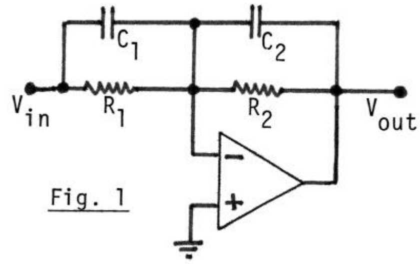
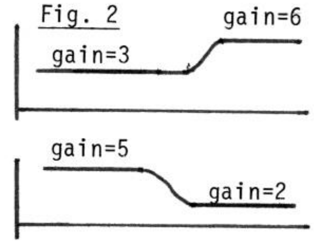


Fig. 1

Fig. 2



To get some idea as to how the circuit works, first observe that at very low frequencies, DC let's say, the capacitors are out of the circuit and we have only an inverting amplifier with gain R_2/R_1. At very high frequencies, the capacitive reactance of the capacitors will be much less than the resistances, and the capacitors will dominate. Since the reactances of the capacitors go as $1/C$, the high frequency gain goes as C_1/C_2.

To go much further, we need the transfer function of the network. This is quite easy. The parallel combination of R_1-C_1 has an impedance $R_1/(1+sC_1R_1)$ while the parallel combination R_2-C_2 is similarily $R_2/(1+sC_2R_2)$. The transfer function is then done much as the inverting amplifier, using the impedances just determined:

$$T(s) = \frac{V_{out}}{V_{in}} = -\frac{R_2/(1+sC_2R_2)}{R_1/(1+sC_1R_1)} = -\frac{R_2(1+sC_1R_1)}{R_1(1+sC_2R_2)} \qquad (1)$$

This is a simple equation which has a zero at $s = -1/R_1C_1$ and a pole at $s = -1/R_2C_2$. We also see that in the limits of s going to zero, we are left with a gain of $-R_2/R_1$, and when s is very large, we get a gain of $-C_1/C_2$, just as we argued above. To get the exact shape of the response, we need to take the magnitude of $T(s)$, which is done by taking $|T(s)| = [T(j\omega)\cdot T(-j\omega)]^{\frac{1}{2}}$, which gives us:

$$|T(s)| = \frac{R_2}{R_1}\left[\frac{1+\omega^2R_1{}^2C_1{}^2}{1+\omega^2R_2{}^2C_2{}^2}\right]^{\frac{1}{2}} = \frac{R_2}{R_1}\left[\frac{1+39.478\,f^2R_1{}^2C_1{}^2}{1+39.478\,f^2R_2{}^2C_2{}^2}\right]^{\frac{1}{2}} \qquad (2)$$

where in the rightmost term of equation (2) we have substituted $2\pi f$ for ω. Note that given equation (2) with the values of R_1, R_2, C_1, and C_2, we can calculate the frequency response at any point.

It should be kept in mind that the rate of transition between one shelf and the other is quite gradual, and never more than 6db octave. In general, it will take several octaves for the transition to take place. Secondly, the equations for the design of the network are straightforward, but not simple in their final form in general. The types of formulas we need are those that will give us 3db frequencies, frequencies for average gains, and gains at the pole and zero frequencies. In all we do below, a frequency may be given in terms of ω or in terms of f, with $\omega = 2\pi f$.

We begin by identifying the pole and zero frequencies as follows:

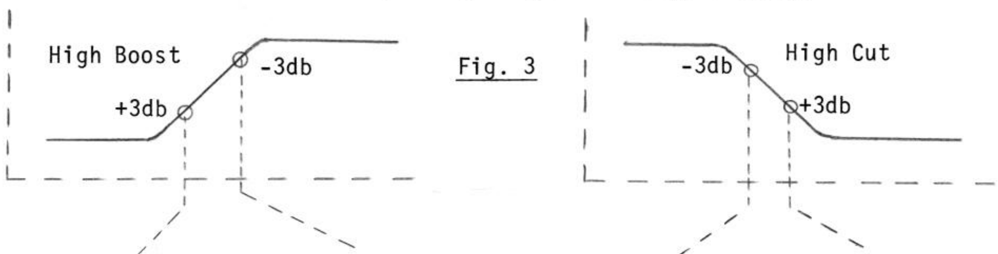
formerly numbered AN-191

$$f_p = 1/2\pi R_2 C_2 \qquad \text{and} \qquad f_z = 1/2\pi R_1 C_1 \qquad (3,4)$$

By substituting $\omega_p = 1/R_2C_2$ and $\omega_z = 1/R_1C_1$ into equation (2) we get the gain at the pole frequency G_p and the gain at the zero frequency G_z as:

$$G_p = \frac{R_2}{R_1}\left[\frac{R_2^2C_2^2 + R_1^2C_1^2}{2R_2^2C_2^2}\right]^{1/2} \qquad G_z = \frac{R_2}{R_1}\left[\frac{2R_1^2C_1^2}{R_2^2C_2^2 + R_1^2C_1^2}\right]^{1/2} \qquad (5,6)$$

Next it is useful to derive the 3db frequencies. These must be done for the separate cases of higher or lower gain at high frequency relative to low frequency. The equations are shown below the corresponding diagrams in Fig. 3 below:



$$f_{\ell+3db} = \frac{1}{2\pi\sqrt{R_1^2C_1^2 - 2R_2^2C_2^2}} \qquad f_{h-3db} = \frac{\sqrt{R_1^2C_1^2 - 2R_2^2C_2^2}}{2\pi R_1R_2C_1C_2}$$

$$f_{\ell-3db} = \frac{1}{2\pi\sqrt{R_2^2C_2^2 - 2R_1^2C_1^2}} \qquad f_{h+3db} = \frac{\sqrt{R_2^2C_2^2 - 2R_1^2C_1^2}}{2\pi R_1R_2C_1C_2}$$

(7,8,9,10)

Also of interest are frequencies that are somehow associated with the center of the transition region. We can consider the center of a linear plot, or the center of a log plot. For the center of a linear plot (for example, a gain of 6 where the shelves are at gains of 2 and 10), we set equation (2) equal to the average of R_2/R_1 and C_1/C_2, which is $(R_1C_1+R_2C_2)/2R_1C_2$. Then solving for the frequency we get:

$$f_a = \frac{1}{2\pi}\sqrt{\frac{R_1^2C_1^2 + 2R_1R_2C_1C_2 - 3R_2^2C_2^2}{R_2^2C_2^2(3R_1^2C_1^2 - 2R_1R_2C_1C_2 - R_2^2C_2^2)}} \qquad (11)$$

The center gain on a log-log plot would be the square root of the product of the gains at low and high frequency, thus the center gain is $\sqrt{(C_1/C_2)(R_2/R_1)}$. Equating this to equation (2) and solving for frequency, we get:

$$f_o = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} \qquad (12)$$

This is a useful result since it is just the square root of the product of the pole and zero frequencies. Thus:

$$f_o = \sqrt{f_z f_p} \qquad (13)$$

Fig. 4 shows an actual example, a boost of four on the high frequency end.

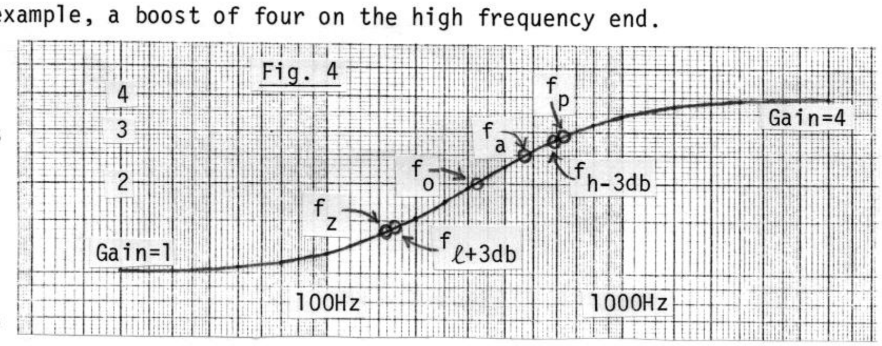


Fig. 4 corresponds to $R_1=R_2=100k$, $C_1=0.01$, and $C_2=0.0025$. Note that the 3db frequencies approach the pole and zero frequencies, and this is even more true as the shelves spread more and more apart. The average gain is $(4+1)/2 = 2.5$ and occurs at f_a, while the center of the log plot is at a gain of 2 at f_o since the ratio of 1:2 is the same as the ratio 2:4. Note the symmetry (except for f_a) about f_o on the log-log plot.