1/f Noise—the flickering candle

MARCH 4, 2013 < HTTPS://WWW.EDN.COM/1-F-NOISE-THE-FLICKERING-CANDLE/>

BY BRUCE TRUMP < HTTPS://WWW.EDN.COM/AUTHOR/BRUCE-TRUMP/>

COMMENTS 23 < HTTPS://WWW.EDN.COM/1-F-NOISE-THE-FLICKERING-CANDLE/#COMMENTS>

The 1/f (one-over-f) low frequency noise region of amplifiers seems just a bit mysterious. Reader “tweet” asked for a discussion of 1/f noise—a challenging topic for a short blog.

It’s also called *flicker noise* , like a flickering candle. Seen on an oscilloscope with a slow sweep it has a wandering baseline (figure 1) because the high frequency noise rides on larger low frequency content. *Pink noise* , another metaphoric name, also suggests the stronger low frequency component. Flicker noise seems ever present in physical systems and life science. Weather/climate patterns, for example, have a 1/f component. I won't attempt to explain why it's found in semiconductors—deep subject!

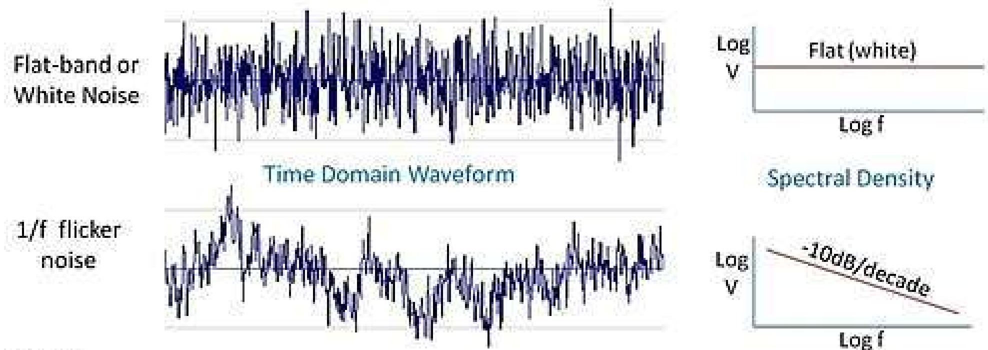

Figure 1.

The spectrum of flicker noise has a nominal slope of -10dB/decade, half that of a single R-C pole. Note that it's the square of the voltage (or power) that declines at a 1/f rate. Noise voltage falls at 1/sqrt(f). The actual slope can vary somewhat but this doesn't greatly change its behavior or the conclusions.

A measured spectrum of flicker noise generally looks lumpy, with dips and valleys. You need to average for long periods to get a reasonably smooth plot. The period of 0.1Hz noise content is 10 seconds, so for a good measurement down to 0.1Hz you need to average many 10-second periods—five minutes or more. For 0.01Hz data, take a long lunch. If you repeat the measurement it will likely look different. Noise is noisy and 1/f noise seems noisier than most other noise (did I write that?).

To calculate total noise, V_B , over a bandwidth (f1 to f2) we integrate the 1/f function, resulting in the natural logarithm of the frequency ratio, f2/f1.

$$V_B^2 = v_a^2 f_a \int_{f1}^{f2} \frac{1}{f}\, df = v_a^2 f_a \cdot ln\left(\frac{f_2}{f_1}\right); \quad \boxed{V_B = v_a \sqrt{f_a \cdot ln\left(\frac{f_2}{f_1}\right)}}$$

Where v_a is the flicker spot noise density at frequency f_a.

Points to ponder…

- Each decade of frequency (or other constant ratio of frequencies) contributes equally to total noise. Each successive decade has lower noise density but more bandwidth.
- From the spectral plot, you might infer that 1/f noise grows boundlessly as you measure for increasingly long periods. It does, but very slowly. Noise from 0.1 to 10Hz doubles (approximately) with a lower bandwidth extended to 3.17e-8 Hz (a one-year period). Add another 6% for ten years.
- It's challenging, but not impossible, to filter 1/f noise. Flicker noise from 0.1Hz to 1kHz (four decades) filtered to 10Hz (two decades) only reduces the noise by 3dB. Resistor values must be kept low for low noise which makes capacitor values large for a low frequency cutoff.

Amplifier noise is a combination of 1/f noise and flat (white) noise. The flat noise continues at low frequency but 1/f noise dominates (figure 2). The 1/f noise continues at high frequency but flat noise dominates. The two blend at the *corner frequency* , adding randomly to make a 3dB increase.

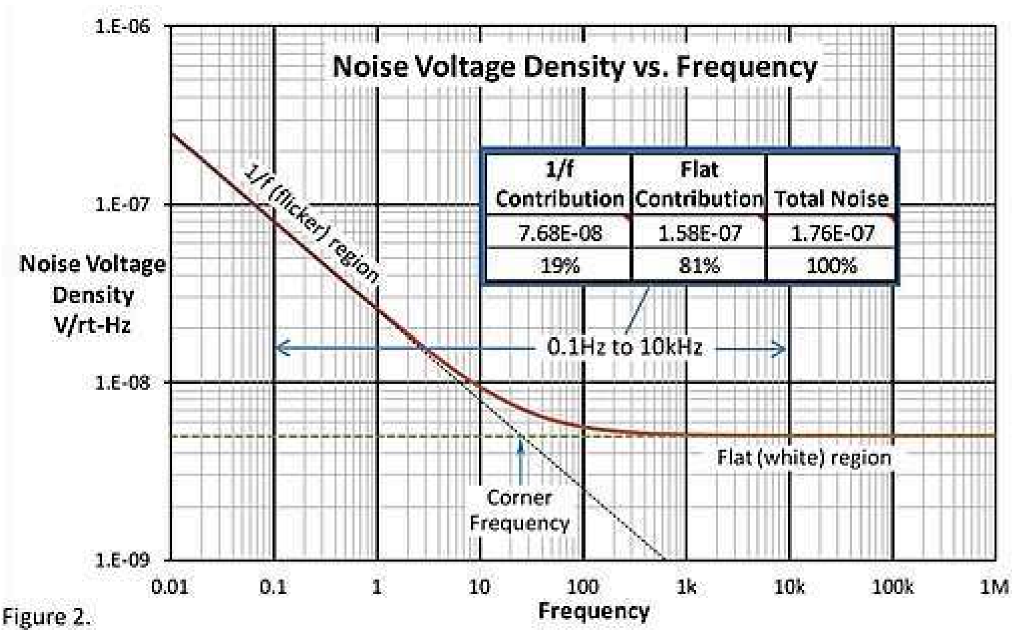

Figure 2.

Amplifier noise is summed over a bandwidth f1 to f2 by integrating the 1/f and flat noise separately over the bandwidth, then combined by the root-sum-of-squares (RSS).

- An N-times increase in flicker noise density increases the corner frequency by N2.
- The total noise from a decade below to a decade above the corner frequency is dominated by the flat-band noise (68%) even though the 1/f noise region "looks bigger."

You can **download an Excel file here < http://e2e.ti.com/blogs-/b/thesignal/archive/2013/03/03/1-f-noise-the-flickering-candle.aspx>** that calculates integrated 1/f noise and flat-band noise, producing a graph and data similar to figure 2. Tinker with it… you'll get a better feel for the issues.

Amplifiers with bipolar (BJT) input stages (**OPA211 < http://www.ti.com/product/opa211>**) generally have lower 1/f noise but new-generation analog IC processes have greatly improved JFET and CMOS transistors. The **OPA140 (JFET) < http://www.ti.com/product/opa140>** and **OPA376 (CMOS) < http://www.ti.com/product/opa376>** op amps, for example, have corner frequencies of 10Hz and 50Hz respectively. **Chopper amplifiers < http://www.ti.com/product/opa2188>** virtually eliminate 1/f noise by correcting offset voltage changes.

Thanks for reading and comments welcome,

Bruce email:

Noise Wonks —I have a question regarding current noise terminology. **Check it out here < http://e2e.ti.com/support/amplifiers/precision-amplifiers/w/design-notes/2362.current-noise-versus-noise-current.aspx>** and offer your opinion.

Check out other interesting topics… **Table of Contents < http://www.ti.com/thesignal-topics>** for all ***The Signal*** blogs.

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23 COMMENTS ON "1/F NOISE—THE FLICKERING CANDLE"

Analoghack

March 5, 2013

I am intrigued by your opening statement: "The 1/f (one-over-f) low frequency noise region of amplifiers seems just a bit mysterious." Could you please recommend any papers available o internet that I could read to help with the "mysterious" part(s)?

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atarifan49

March 5, 2013

I think the mysterious part comes from the following excerpt from Design w/ Op Amps & Analc
Integrated Circuits (by Sergio Franco) which shares this about Flicker Noise, "…present in all
as well as in some passive devices and has various origins,

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davee

March 6, 2013

"Design w/ Op Amps & Analog Integrated Circuits (by Sergio Franco)"
is a very good book, I highly recommend it.

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Bruce Trump

March 6, 2013

Analoghack, you made me think. Why, indeed, do I find 1/f noise mysterious? It's ubiquitous, 1
in so many desperate disciplines. I find its properties intriguing. It's also a great challenge for
processing engineers with opportunity for improvement.

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Bruce Trump

March 6, 2013

Woops… I meant disparate, not desperate. Funny…I'm yet another victim of automatic spellir
correction.

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BradWood

March 7, 2013

I don't know of any persuasive explanation of 1/f, and it's not from lack of theorizing and hand
waving across many decades (no pun intended) of work by physicists and engineers. Periodic
someone will proclaim an explanation, usually to have it demoli

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edwinpettis

March 8, 2013

If the quote from Mr. Sergio's textbook is correct, he is only partially correct about resistors ha
1/f noise. All resistor types except properly made wire wound resistors have flicker noise. The
amount of flicker noise in resistors depends on the ty

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souf

March 9, 2013

First, thank you Bruce for an engaging discussion on noise. And yes there's a lot more to be s
about 1/f in passive components and IC's but I think Mr. Franco does an outstanding job at
explaining it with and without mathematical formulas. I was fortun

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souf

March 9, 2013

Come to think of it, another interesting topic would be pop corn noise (burst noise) and what v
mean when we say process defects, things like more details on the erratic jump of the transis
between 2 values of Beta (Hfe). Is anyone going to be able to

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PBr

March 11, 2013

Here is a review paper on 1/f noise with math and physics:
**http://arxiv.org/ftp/physics/papers/0204/0204033.pdf <
http://arxiv.org/ftp/physics/papers/0204/0204033.pdf>**

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MISSIONCAT

March 12, 2013

1/f noise is very pervasive, however appears to be a purely physical phenomenon. I tried runr
FFT's of the fractional part of the irrational numbers pi and SQRT(2) out to 200,000 digits and
very-flat white noise. Apparently some, if not all, irratio

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Roy McCammon

March 12, 2013

Irrational numbers are more likely to be mediocre pseudo-random number generators. For
example, there are several algorithms for determining the digits of pi. If you want good pseud
random number generators, one source is Numerical Recipes at NR.com.

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Roy McCammon

March 12, 2013

The mysterious part is that if the power goes truly as 1/F no matter how low F goes then the p
must eventually become infinite. But it doesn't. The reason is that the device is turned off befo
that time. When you turn the device on, the 1/F noise

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CCarpenter

March 17, 2013

Flicker noise in the physics of spelling.

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dates

March 20, 2013

Hi Bruce
Which real-world systems benefit (the most) from using a chopper amp. i.e. which physical quantities that get measured are the ones where the 1/f noise of the op-amp is a significant-e factor, such that by changing an ordinary op-amp to use a

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Bruce Trump

March 28, 2013

Roy—You've made some interesting and thought-provoking comments but I can't agree with y basic premise. An amplifier with 1/f noise has no memory or sense of history. It does not know long it has been on (we're ignoring possible aging effects). Wha

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Guru of Grounding

March 28, 2013

I think you are talking about "excess" noise here. All resistors, regardless of construction or composition, make the same thermal agitation or "Johnson" noise. Only when DC begins to fl the aforementioned make a difference … and yes, when even mod

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Guru of Grounding

March 28, 2013

Another excellent piece Bruce! For those who aren't aware, so-called "pink noise" (rolling off a dB/octave or 10 dB/decade) is a frequently-used test signal for audio systems and loudspeak The spectral energy distribution in natural music (as oppos

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edwinpettis

March 31, 2013

Contrary to 1/f graphs indicating an ever increasing noise voltage potential, it is quite impossil Bob Pease and I were doing some noise measurements for a project I was working on and w came to two conclusions. The mechanism which causes 1/f noise

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arosnes

April 9, 2013

You would not expect the noise voltage to increase. Try this experiment instead:
White noise can be averaged/filtered by multiple samples to ge a more accurate value.
Pink noise will always have lower frequency components that are lower than your longest

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izpura

June 29, 2016

“Following the u201cflickering candleu201d words, I decided to enter a comment about the nc appearing in this forum that could be useful for those that besides to know u201chow to do itu also like to know u201cwhy to do it sou201d.nAs it sh

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izpura

June 29, 2016

“The missing references:n[1] J. B. Johnson, Phys. Rev., 32, 97 (1928).n[2] H. Nyquist, Phys. I 32, 110 (1928).n[3] J. R. Pierce, Bell System Technical Journal, 27, 158 (1948).”

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izpura

June 29, 2016

“Concerning the ubiquitous noise called u201c1/f excess noiseu201d to design fluctuations of resistance (u2206R) I would use u201c1/f RESISTANCE NOISEu201d in a forum like this. Bc by the need of fluctuating VOLTAGE u2206V to measure u201csome

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