[1/f Noise—the flickering candle]

[Bruce Trump] - March 04, 2013

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!

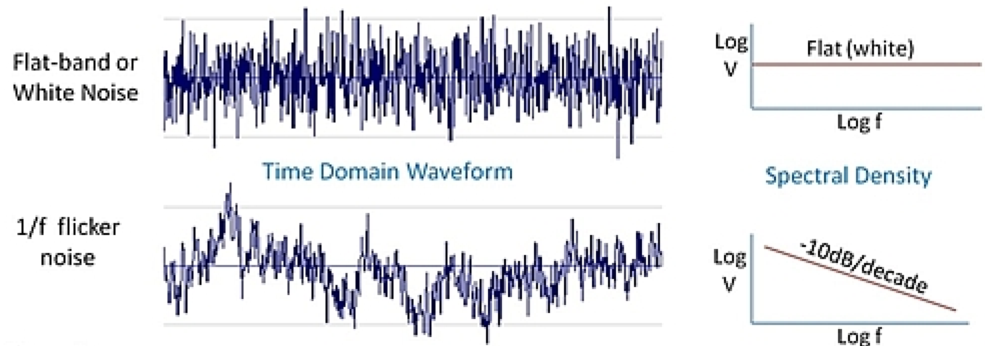

Figure 1.

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.

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

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.

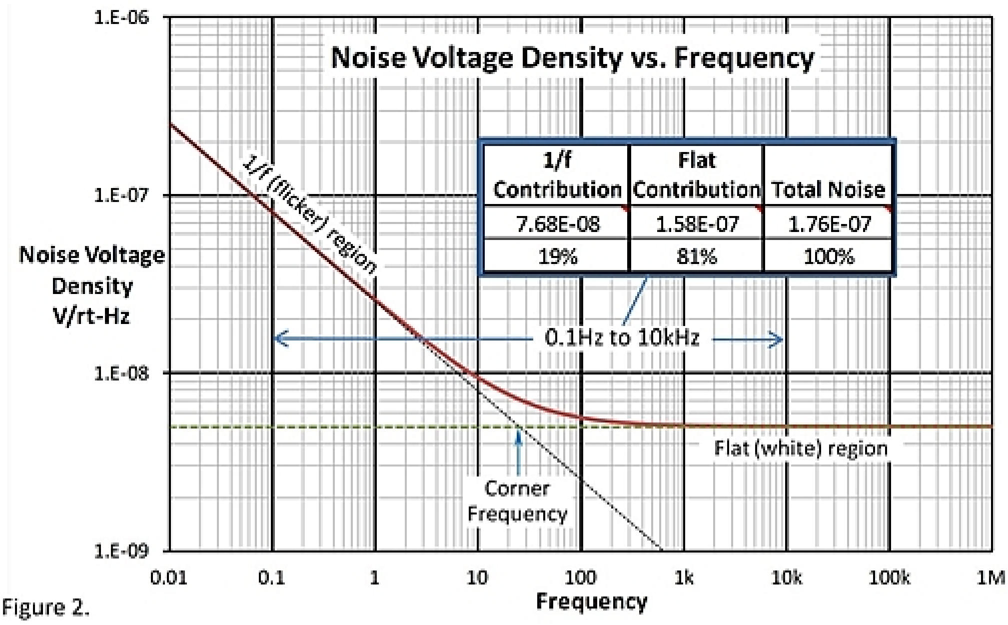

Figure 2.

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 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) generally have lower 1/f noise but newgeneration analog IC processes have greatly improved JFET and CMOS transistors. The OPA140 (JFET) and OPA376 (CMOS) op amps, for example, have corner frequencies of 10Hz and 50Hz respectively. Chopper amplifiers virtually eliminate 1/f noise by correcting offset voltage changes.

Thanks for reading and comments welcome,

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Noise Wonks—I have a question regarding current noise terminology. Check it out here and offer your opinion.

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