Noise measurements for LEDs and zener diodes

v. 1.3
Added more devices. Introductory text not changed to reflect
this.

v. 1.4.
Added new experiment (number 2) at the end.

EXPERIMENT 1

DESCRIPTION OF TEST RIG

The test rig uses three current sources of approx. 1, 5 and 20 mA
built using low-noise BJTs (BC559) to feed the device under test
(DUT) alternatingly. The noise was measured using two op amps in
in non-inverting configuration cascaded, both having a gain of 34,
making a gain of 1156 in total. The first op amp is a very-low-noise
model (LT1115) and uses a gain resistor of only 10 Ohms in the feedback
network. The gain resistor is thus 330 Ohms which works since the op
amp is only expected to output very low-level signals. The second op
amp is a low-noise type (NE5534) with gain and feedback resistors of
100 Ohms and 3.3 kOhms. The output was measured using a PC soundcard
(Creative Audigy LS in 16-bit 44.1 kHz mode). Each measurement consists
of a 10 second capture of the soundcard input and the RMS value for
this 10 s. signal was computed. The program was calibrated (using a
sine wave and an oscilloscope) to give aprroximately correct voltage
readings and all measurements were divided by 1156 to give the equivalent
input RMS noise at the first op amp, ie. at the DUT. No extra filters
except what is on the soundcard were used.

TEST METHOD

A spectrum of LED types ranging from IR to blue and of approximately
the same type were measured. All LEDS were selected to have an max
If of at least 20 mA, since this current was used in the test. Further
four 0.5W types of zener diodes were tested, two of them (5.6 and 6.8 V)
were deliberately selected close to each other but such that the 5.6 V
diode should be expected to have true zener breakdown and the 6.8 V one
to have avalanche breakdown. The other two were selected to be far away
from this "transition region". Two 1.3W zeners were also tested to see
how the power rating affects noise figures.

For each type of DUT, two devices (denoted #1 and #2 and presumably
from the same batch) were tested at the three test currents 1, 5 and
20 mA and the equivalent noise at the DUT was measured and calculated
as described above. For each combination of device and current, five

10-second measurements were made.

For reference, the voltage drop at each test current
was also measured for one device of each type.

MEASUREMENTS

All values are RMS values, five measurements for each case.

Idle noise:

Measured idle noise of amplifier with grounded input:
0.19 0.19 0.19 0.19 0.18 uV
(The theoretical max value was calculated to 0.16 uV for
20kHz bandwidth and 0.22 uB for 40 kHz bandwidth).

Measured idle noise of amplifier with 100 Ohm source resistor:
0.26 0.25 0.24 0.26 0.26 uV
(The theoretical max value was calculated to 0.20 uV for
20kHz bandwidth and 0.28 uB for 40 kHz bandwidth).

Diodes:

1N4148 (unknown brand):
#1 @ 1mA: 0.28 0.28 0.28 0.27 0.27 uV
#1 @ 5mA: 0.25 0.25 0.22 0.22 0.22 uV
#1 @ 20mA: 0.24 0.21 0.22 0.25 0.23 uV
#2 @ 1mA: 0.38 0.27 0.28 0.26 0.29 uV (Vf = 0.57 V)
#2 @ 5mA: 0.23 0.22 0.23 0.23 0.23 uV (Vf = 0.65 V)
#2 @ 20mA: 0.23 0.21 0.21 0.21 0.24 uV (Vf = 0.75 V)

1N4004 (unknown brand):
#1 @ 1mA: 0.31 0.29 0.29 0.29 0.29 uV
#1 @ 5mA: 0.26 0.24 0.26 0.26 0.25 uV
#1 @ 20mA: 0.27 0.23 0.23 0.24 0.23 uV
#2 @ 1mA: 0.29 0.25 0.25 0.27 0.26 uV (Vf = 0.55 V)
#2 @ 5mA: 0.29 0.24 0.25 0.23 0.23 uV (Vf = 0.62 V)
#2 @ 20mA: 0.23 0.23 0.22 0.21 0.22 uV (Vf = 0.71 V)

LEDs:

Brand is Everlight unless otherwise stated.

IR204/P1 (IR):
#1 @ 1mA: 3.7 3.7 3.7 3.7 3.7 uV
#1 @ 5mA: 0.67 0.66 0.65 0.66 0.66 uV
#1 @ 20mA: 0.24 0.23 0.24 0.23 0.23 uV
#2 @ 1mA: 3.8 3.8 3.7 3.7 3.7 uV (Vf = 1.05 V)
#2 @ 5mA: 0.65 0.64 0.64 0.64 0.64 uV (Vf = 1.11 V)
#2 @ 20mA: 0.24 0.25 0.23 0.24 0.22 uV (Vf = 1.17 V)

EL202HD (red):
#1 @ 1mA: 0.31 0.32 0.31 0.31 0.32 uV
#1 @ 5mA: 0.26 0.26 0.27 0.27 0.27 uV
#1 @ 20mA: 0.39 0.36 0.37 0.36 0.37 uV
#2 @ 1mA: 0.39 0.37 0.38 0.38 0.35 uV (Vf = 1.82 V)
#2 @ 5mA: 0.32 0.30 0.30 0.30 0.31 uV (Vf = 1.89 V)
#2 @ 20mA: 0.41 0.40 0.41 0.41 0.46 uV (Vf = 2.09 V)

EL1254HD/T2 (red):
#1 @ 1mA: 0.36 0.35 0.35 0.34 0.35 uV
#1 @ 5mA: 0.30 0.29 0.31 0.32 0.30 uV
#1 @ 20mA: 0.51 0.56 0.54 0.55 0.53 uV
#2 @ 1mA: 0.53 0.42 0.39 0.41 0.40 uV (Vf = 1.82 V)
#2 @ 5mA: 0.30 0.30 0.31 0.29 0.29 uV (Vf = 1.90 V)
#2 @ 20mA: 0.42 0.42 0.42 0.43 0.43 uV (Vf = 2.17 V)

L934ID/B (red):
#1 @ 1mA: 0.29 0.28 0.28 0.27 0.28 uV
#1 @ 5mA: 0.27 0.24 0.24 0.23 0.24 uV
#1 @ 20mA: 0.39 0.32 0.29 0.48 0.29 uV
#2 @ 1mA: 0.34 0.28 0.28 0.28 0.27 uV (Vf = 1.64 V)
#2 @ 5mA: 0.24 0.24 0.25 0.24 0.25 uV (Vf = 1.72 V)
#2 @ 20mA: 0.30 0.25 0.27 0.30 0.28 uV (Vf = 1.89 V)
(Brand is Kingbright)

EL204ID (red-orange):
#1 @ 1mA: 0.31 0.30 0.31 0.31 0.31 uV
#1 @ 5mA: 0.25 0.26 0.26 0.26 0.24 uV
#1 @ 20mA: 0.41 0.41 0.48 0.40 0.41 uV
#2 @ 1mA: 0.35 0.31 0.29 0.30 0.32 uV (Vf = 1.64 V)
#2 @ 5mA: 0.25 0.26 0.27 0.26 0.30 uV (Vf = 1.74 V)
#2 @ 20mA: 0.40 0.40 0.39 0.40 0.41 uV (Vf = 1.90 V)

EL204YD (yellow):
#1 @ 1mA: 0.42 0.30 0.29 0.29 0.28 uV
#1 @ 5mA: 0.28 0.26 0.25 0.33 0.27 uV
#1 @ 20mA: 0.42 0.39 0.39 0.40 0.40 uV
#2 @ 1mA: 0.31 0.30 0.31 0.30 0.31 uV (Vf = 1.78 V)
#2 @ 5mA: 0.28 0.47 0.28 0.26 0.25 uV (Vf = 1.87 V)
#2 @ 20mA: 0.34 0.34 0.35 0.34 0.34 uV (Vf = 2.02 V)

EL204GD (green):
#1 @ 1mA: 0.68 0.50 0.50 0.47 0.46 uV
#1 @ 5mA: 0.35 0.30 0.28 0.28 0.29 uV
#1 @ 20mA: 0.36 0.35 0.35 0.35 0.35 uV
#2 @ 1mA: 0.46 0.46 0.44 0.44 0.41 uV (Vf = 1.82 V)
#2 @ 5mA: 0.36 0.33 0.32 0.33 0.32 uV (Vf = 1.92 V)
#2 @ 20mA: 0.39 0.40 0.39 0.41 0.40 uV (Vf = 2.12 V)

EL1254GD/T2 (green):
#1 @ 1mA: 0.36 0.36 0.34 0.33 0.34 uV (Vf = 1.84 V)
#1 @ 5mA: 0.40 0.40 0.38 0.41 0.40 uV (Vf = 1.96 V)
#1 @ 20mA: 1.8 1.9 1.9 1.9 2.1 uV (Vf = 2.20 V)
#2 @ 1mA: 0.46 0.41 0.36 0.37 0.39 uV (Vf = 1.82 V)
#2 @ 5mA: 0.41 0.42 0.35 0.34 0.31 uV (Vf = 1.93 V)
#2 @ 20mA: 0.48 0.50 0.48 0.50 0.51 uV (Vf = 2.27 V)

(Measured Vf of both devices for potential correlation
with differing noise figs. at 20 mA. Obviously no
such correlation found.)

EL204UBD (blue):
#1 @ 1mA: 4.6 4.5 4.6 4.5 4.6 uV
#1 @ 5mA: 3.2 3.2 3.2 3.2 3.2 uV
#1 @ 20mA: 2.8 2.8 2.7 2.7 2.7 uV
#2 @ 1mA: 4.4 4.4 4.3 4.2 4.3 uV (Vf = 3.26 V)
#2 @ 5mA: 3.1 3.2 3.2 3.1 3.2 uV (Vf = 3.44 V)
#2 @ 20mA: 2.9 2.8 2.8 2.8 2.7 uV (Vf = 3.69 V)

Zeners:

(All zeners of brand Temic.)

BZX55/C2V7 (0.5W 2.7V):
#1 @ 1mA: 1.1 1.1 1.1 1.1 1.1 uV
#1 @ 5mA: 1.0 0.88 0.85 0.86 0.87 uV
#1 @ 20mA: 1.0 0.81 0.72 0.72 1.1 uV
#2 @ 1mA: 1.2 1.1 1.1 1.1 1.1 uV (Vr = 2.03 V)
#2 @ 5mA: 0.91 0.88 0.87 0.86 0.85 uV (Vr = 2.50 V)
#2 @ 20mA: 1.1 0.80 0.77 0.73 0.71 uV (Vr = 3.02 V)

BCX55/C3V9 (0.5W 3.9V):
#1 @ 1mA: 1.7 1.8 1.7 1.6 1.6 uV
#1 @ 5mA: 1.1 1.1 1.1 1.2 1.1 uV
#1 @ 20mA: 0.94 9.76 0.84 0.79 0.77 uV
#2 @ 1mA: 1.6 1.6 1.6 1.5 1.6 uV (Vr = 3.17 V)
#2 @ 5mA: 1.2 1.1 1.1 1.1 1.1 uV (Vr = 3.83 V)
#2 @ 20mA: 0.97 0.78 0.86 0.76 0.77 uV (Vr = 4.45 V)

BZX55/C5V6 (0.5W 5.6V):
#1 @ 1mA: 5.3 5.3 5.3 5.3 5.3 uV
#1 @ 5mA: 2.9 2.9 2.9 2.9 2.9 uV
#1 @ 20mA: 1.7 1.6 1.6 1.6 1.6 uV
#2 @ 1mA: 5.3 5.3 5.3 5.3 5.3 uV (Vr = 5.68 V)
#2 @ 5mA: 2.9 2.9 2.9 2.9 2.9 uV (Vr = 5.77 V)
#2 @ 20mA: 1.8 1.6 1.6 1.6 1.6 uV (Vr = 5.81 V)

BZX55/C6V2 (0.5W 6.2V):
#1 @ 1mA: 9.0 8.9 8.9 8.9 8.9 uV
#1 @ 5mA: 3.7 3.6 3.6 3.6 3.6 uV
#1 @ 20mA: 1.7 1.6 1.6 1.6 1.6 uV
#2 @ 1mA: 9.4 9.4 9.3 9.3 9.3 uV (Vr = 6.31 V)
#2 @ 5mA: 3.7 3.7 3.8 3.7 3.7 uV (Vr = 6.33 V)
#2 @ 20mA: 2.6 1.8 1.8 1.8 1.7 uV (Vr = 6.38 V)

BZX55/C6V8 (0.5W 6.8V):
#1 @ 1mA: 16   16   16   16   16   uV
#1 @ 5mA: 21   21   21   21   21   uV
#1 @ 20mA: 5.8 5.5 5.5 5.5 5.6 uV
#2 @ 1mA: 25   25   25   25   25   uV (Vr = 6.93 V)
#2 @ 5mA: 13   13   13   13   13   uV (Vr = 6.96 V)

#2 @ 20mA: 4.6 4.7 4.5 4.5 4.4 uV (Vr = 7.00 V)
(Rechecked both devices due to their inconsistent
behaviour for 1 and 5mA).

BCX55/C7V5 (0.5W 7.5V):
#1 @ 1mA: 116 116 116 116 119 uV
#1 @ 5mA: 50 50 50 50 50 uV
#1 @ 20mA: 25 24 24 24 24 uV
#2 @ 1mA: 118 117 116 117 116 uV (Vr = 7.58 V)
#2 @ 5mA: 50 50 50 50 50 uV (Vr = 7.62 V)
#2 @ 20mA: 18 18 18 18 18 uV (Vr = 7.72 V)
(The high readings seem to correlate with scope
readings. These devices were possibly of a
different brand.)

8.2V (unknown brand, probably 0.5W):
#1 @ 1mA: 108 109 109 109 109 uV
#1 @ 5mA: 49 49 48 48 48 uV
#1 @ 20mA: 15 15 14 14 14 uV
#2 @ 1mA: 108 107 107 106 106 uV (Vr = 7.93 V)
#2 @ 5mA: 39 39 39 39 39 uV (Vr = 7.97 V)
#2 @ 20mA: 14 13 13 13 13 uV (Vr = 8.10 V)

BZX55/C12   (0.5W 12V):
#1 @ 1mA: 0.35 0.37 0.37 0.39 0.39 uV
#1 @ 5mA: 0.30 0.28 0.28 0.28 0.30 uV
#1 @ 20mA: 0.24 0.25 0.25 0.26 0.25 uV
#2 @ 1mA: 0.32 0.33 0.32 0.33 0.32 uV (Vr = 11.32 V)
#2 @ 5mA: 0.26 0.26 0.27 0.32 0.26 uV (Vr = 11.37 V)
#2 @ 20mA: 0.25 0.26 0.28 0.24 0.30 uV (vr = 11.42 V)

BZX85/C2V7 (1.3W 2.7V):
#1 @ 1mA: 0.77 0.77 0.77 0.77 0.76 uV
#1 @ 5mA: 0.62 0.61 0.63 0.61 0.60 uV
#1 @ 20mA: 0.55 0.55 0.54 0.55 0.55 uV
#2 @ 1mA: 0.78 0.78 0.78 0.78 0.78 uV (Vr = 1.30 V)
#2 @ 5mA: 0.62 0.62 0.61 0.62 0.62 uV (Vr = 1.61 V)
#2 @ 20mA: 0.57 0.56 0.57 0.56 0.56 uV (Vr = 1.92 V)

BZX85/C12 (1.3W 12V):
#1 @ 1mA: 0.49 0.53 0.48 0.50 0.52 uV
#1 @ 5mA: 0.54 0.55 0.58 0.46 0.48 uV
#1 @ 20mA: 0.44 0.35 0.38 0.36 0.33 uV
#2 @ 1mA: 0.42 0.43 0.46 0.48 0.41 uV (Vr = 9.84 V)
#2 @ 5mA: 0.40 0.35 0.35 0.37 0.29 uV (Vr = 9.89 V)
#2 @ 20mA: 0.34 0.33 0.31 0.30 0.31 uV (Vr = 9.94 V)

Miscellaneous:

TL431 (Ref tied to cathode to work as 2.5V zener diode):
#1 @ 1mA: 20 20 20 20 20 uV
#1 @ 5mA: 20 20 20 20 20 uV
#1 @ 20mA: 20 20 20 20 20 uV
#2 @ 1mA: 20 20 20 20 20 uV
#2 @ 5mA: 20 20 20 20 20 uV

#2 @ 20mA: 20 20 20 20 20 uV
(No cheating, the measurements actually were so
consistent.)

TL431 (strapped as 5V ref. using two 1kOhm resistors):
#1 @ 1mA: 3.2 3.2 3.2 3.2 3.2 uV
#1 @ 5mA: 41   41   41   41   41   uV
#1 @ 20mA: 42   42   42   42   42   uV
#2 @ 1mA: 3.2 3.3 3.2 3.3 3.3 uV
#2 @ 5mA: 41   41   41   41   41   uV
#2 @ 20mA: 42   42   42   42   42   uV

BC549 BE diode forward biased:
#1 @ 1mA: 0.24 0.24 0.24 0.24 0.24 uV
#1 @ 5mA: 0.22 0.23 0.22 0.24 0.23 uV
#1 @ 20mA: 0.22 0.21 0.20 0.22 0.20 uV
#2 @ 1mA: 0.23 0.23 0.25 0.24 0.24 uV (Vf = 0.73 V)
#2 @ 5mA: 0.23 0.23 0.23 0.23 0.22 uV (Vf = 0.78 V)
#2 @ 20mA: 0.21 0.22 0.21 0.20 0.21 uV (Vf = 0.86 V)

BC549 BE diode reverse biased:
#1 @ 1mA: 56   59   59   56   57   uV
#1 @ 5mA: 8.1 8.2 8.3 8.4 8.4 uV
#1 @ 20mA: 4.7 4.7 4.8 4.9 4.8 uV
#2 @ 1mA: 60   56   54   52   50   uV (Vr = 8.33 V)
#2 @ 5mA: 18   17   16   15   14   uV (Vr = 8.39 V)
#2 @ 20mA: 4.8 4.8 4.8 4.9 4.8 uV (Vr = 8.68 V)

EXPERIMENT 2

TEST RIG

Almost the same set up as in experiment 1, but one single current source was used with a 500 Ohm trim pot in series with 10 Ohm as emitter resistor.

TEST METHOD

One or two devices of selected LED types were tested at currents 2, 4, 6 and 8 mA with the purpose of spotting a tendency towards a noise optimum at some current. Depending on these results, measurements at certain other currents were sometimes added. In those cases where two devices were tested, device numbers may be swapped compared to experiment 1. Voltage drop was added to the tables in these measurements. As previously, five rms noise readings over 10 s each were taken.

MEASUREMENTS

EL202HD (red):
#1 1.5mA 1.86V Noise: 0.32 0.34 0.30 0.31 0.34 uV
#1 2.0mA 1.87V Noise: 0.31 0.30 0.31 0.31 0.31 uV
#1 3.0mA 1.90V Noise: 0.30 0.29 0.29 0.27 0.28 uV
#1 4.0mA 1.92V Noise: 0.28 0.28 0.28 0.27 0.27 uV
#1 5.0mA 1.94V Noise: 0.30 0.28 0.28 0.28 0.29 uV
#1 6.0mA 1.96V Noise: 0.30 0.30 0.28 0.28 0.29 uV
#1 8.0mA 1.99V Noise: 0.30 0.33 0.32 0.30 0.31 uV
#1 10.0mA 2.03V Noise: 0.71 0.68 0.66 0.63 0.62 uV

#2 2.0mA 1.88V Noise: 0.35 0.28 0.28 0.28 0.28 uV
#2 3.0mA 1.90V Noise: 0.28 0.29 0.26 0.28 0.27 uV
#2 4.0mA 1.92V Noise: 0.27 0.28 0.27 0.27 0.27 uV
#2 5.0mA 1.94V Noise: 0.28 0.27 0.27 0.27 0.26 uV
#2 6.0mA 1.95V Noise: 0.27 0.28 0.26 0.26 0.26 uV
#2 8.0mA 1.98V Noise: 0.31 0.30 0.30 0.32 0.30 uV

L934ID/B (red):
#1 2.0mA 1.70V Noise: 0.28 0.25 0.28 0.25 0.27 uV
#1 4.0mA 1.75V Noise: 0.43 0.27 0.25 0.27 0.26 uV
#1 5.0mA 1.76V Noise: 0.39 0.25 0.25 0.25 0.24 uV
#1 6.0mA 1.78V Noise: 0.27 0.31 0.25 0.27 0.25 uV
#1 8.0mA 1.80V Noise: 0.34 0.31 0.30 0.30 0.32 uV

EL204ID (orange-red):
#1 2.0mA 1.71V Noise: 0.42 0.31 0.27 0.27 0.27 uV
#1 4.0mA 1.76V Noise: 0.30 0.32 0.32 0.29 0.27 uV
#1 5.0mA 1.78V Noise: 0.27 0.26 0.26 0.28 0.27 uV
#1 6.0mA 1.80V Noise: 0.28 0.27 0.27 0.28 0.43 uV
#1 7.0mA 1.82V Noise: 0.31 0.29 0.27 0.30 0.28 uV
#1 8.0mA 1.83V Noise: 0.60 0.35 0.36 0.35 0.33 uV

#2 2.0mA 1.71V Noise: 0.26 0.34 0.28 0.33 0.30 uV
#2 4.0mA 1.76V Noise: 0.27 0.26 0.28 0.62 0.40 uV
#2 5.0mA 1.78V Noise: 0.37 0.26 0.37 0.27 0.25 uV
#2 6.0mA 1.80V Noise: 0.29 0.28 0.27 0.26 0.26 uV
#2 7.0mA 1.81V Noise: 0.30 0.35 0.44 0.28 0.32 uV
#2 8.0mA 1.82V Noise: 0.40 0.35 0.36 0.32 0.35 uV

EL204YD (yellow):
#1 1.5mA 1.83V Noise: 0.32 0.31 0.41 0.31 0.28 uV
#1 2.0mA 1.85V Noise: 0.26 0.26 0.26 0.60 0.26 uV
#1 3.0mA 1.88V Noise: 0.26 0.28 0.25 0.28 0.24 uV
#1 4.0mA 1.90V Noise: 0.30 0.25 0.26 0.26 0.24 uV
#1 5.0mA 1.92V Noise: 0.28 0.28 0.28 0.26 0.27 uV
#1 6.0mA 1.93V Noise: 0.29 0.27 0.27 0.27 0.28 uV
#1 8.0mA 1.96V Noise: 0.31 0.31 0.31 0.32 0.32 uV

EL204GD (green):
#1 2.0mA 1.89V Noise: 0.39 0.36 1.41 0.36 0.36 uV
#1 4.0mA 1.95V Noise: 0.48 0.41 0.34 0.34 0.32 uV
#1 5.0mA 1.97V Noise: 0.33 0.33 0.32 0.31 0.31 uV
#1 6.0mA 1.99V Noise: 0.30 0.31 0.30 0.29 0.30 uV
#1 7.0mA 2.02V Noise: 0.33 0.32 0.35 0.31 0.30 uV
#1 8.0mA 2.04V Noise: 0.34 0.35 0.33 0.32 0.31 uV