Shot Noise

by Kenneth A. Kuhn
Feb. 18, 2013

Shot noise is a phenomenon related to the fact that an electric current, rather than being a continuum, is comprised of a discrete number of charged particles passing a given point in a unit of time. From one unit time to the next the exact number of charged particles passing that point will randomly vary. For relatively high currents the effect of shot noise is small as there are a huge number of charged particles involved that dwarfs the effect of a quantum charge. However, at low currents the discrete nature of charged particles shows up and shot noise can be significant. The equation for shot noise is given in Equation 1.

$$I_{Sn} = \sqrt{2qIB} \tag{1}$$

where:

- I_{Sn} is the rms shot noise current
- q is the magnitude of a charge quanta, 1.602E-19 coulombs
- I is the current in amperes
- B is the noise bandwidth of the measurement in Hertz

Note that there is no consistent symbol for shot noise. The symbol used here, I_{Sn}, is an attempt to make it clear. The student should understand that other will refer to it with different symbols.

Doing a units check of what is inside the radical give us the product of coulombs times (coulombs/second) * (1/seconds) = (coulombs/second)^2 which is current in amperes after we take the square root.

As an example, the table below shows the shot noise of a range of currents over a 1 MHz noise bandwidth.

Current	**Shot noise**
1 pA	566 fArms
1 nA	17.9 pArms
1 uA	566 pArms
1 mA	17.9 nArms
1 A	566 nArms

Note that the magnitude of the shot noise relative to the direct current becomes less as the current increases. That is because the current increases linearly while shot noise only increases as the square-root of current. In very low-level signal applications where signals are in the femto-ampere range, shot noise can become even more significant than thermal noise. Shot noise is not a function of temperature so cooling has no effect.

Shot Noise

One often used example of shot noise is rain falling on a surface such as a tin roof. When the rain is only coming down in widely scattered drops then each rain drop is heard individually – that is analogous to discrete electrons passing a given point. As the rain picks up, the sounds of the individual drops become so numerous as to merge and finally become a roar during heavy rain.

Another example of shot noise is popcorn. Each pop is a random discrete event. A “current” is formed by a lot of pops happening closely spaced in time. The number of pops per second varies in a discrete manner. Do not confuse this example with what is sometimes called popcorn noise or burst noise. Those are sporadic random events often the result of some manufacturing defect or some not fully understood as yet physical phenomenon. In audio systems they make a sound akin to a popcorn pop, thus the name.

An electronic example of shot noise is photons striking a sensitive optical detector. The photon count per second could be in the low single digits or less for a very faint light such as from a distant star.

At very low currents shot noise follows a Poisson distribution rather than Gaussian. As the current increases the distribution evolves towards Gaussian.