ELE2EMI 2007
Electronics Measurements and Instrumentation

17 Noise

References

- *Berlin and Getz*, chapter 4, pages 65-100.
- *Carr*, chapter 15, pages 373-390.

Outline

1. Noise Sources.
2. Noise Model.
3. Noise Measurements.
4. Minimizing Noise.

17.1 Noise Sources

Any electronic system is affected by many noise sources. These may be classified as follows.

Transmitted: Received with, and superimposed on, the original signal.

Intrinsic: Originates within the electronic devices in the system.

Interference: Picked up by the system from outside, but not through the designated inputs.

We will concentrate on Intrinsic and Interference noise sources, as they account for the origin of transmitted noise also.

17.1.1 Intrinsic Noise

Intrinsic noise may be classified according to how its intensity varies with frequency. Two common patterns are white noise and pink noise.

White: The amplitude of white noise hardly varies with frequency.

Pink: By contrast, pink noise is strong at low frequencies, and weakens as frequency increases.

We consider two kinds of *white* noise, **thermal** noise and **shot** noise. These are reasonably well understood, and can be precisely calculated in advance.

Thermal: Caused by the radom component of the motion of electrons in a conductor, which increases with temperature. This random current produces a noise voltage that, by Ohm's law, increases with the resistance of the conductor. So thermal noise is also named **resistance noise**. It is associated particularly with carbon and wire-wound resistors. Lower noise resistors can be made of glass or metal-film.

Yet other names for thermal noise are **Johnson** and **Nyquist** noise, after two prominent researchers into the nature and effects of thermal noise.

The RMS voltage v_{RMS} generated by thermal noise is related to *temperature* T, *resistance* R and the *effective noise bandwidth* Δf as follows:

$$v_{RMS} = \sqrt{4k.T.R.\Delta f}$$

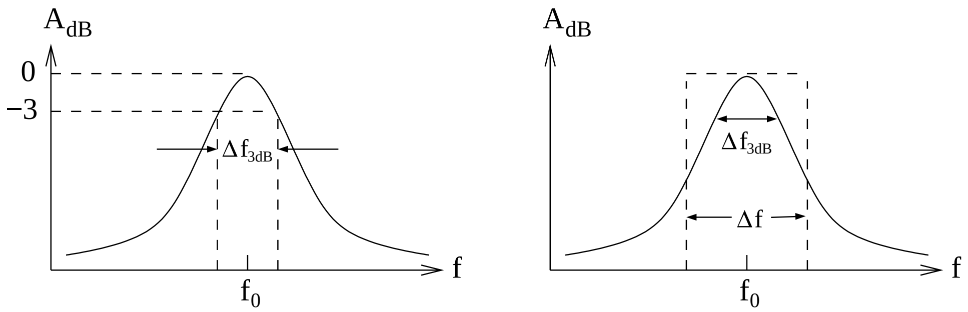
The value of k is Boltzmann's constant, 1.38×10^{-23} J/K. (Joule per Kelvin. That is, W/Hz/K, Watt per Hertz per Kelvin.)

So the *power* dissipated in the resistance R equals

$$P = 4k.T.\Delta f$$

Although thermal noise, being white, is very broadband, its effect on a circuit, as with all inputs, both signals and noise, is limited by the circuit's frequency response. The **effective noise bandwidth** Δf of a system is defined as the width of a rectangle that has the same height and area as the system's frequency response curve. For a variety of systems, the effective noise bandwidth is approximately 60% greater than the -3 dB bandwidth. See the next figure.

Frequency response of a tuned circuit



−3 dB bandwidth

Noise bandwidth

Shot: Due to the small local fluctuations in DC current, shot noise is also called **Schottky**, **Schrot**, and **partition** noise. The RMS shot noise current i_{RMS} is given by:

$$i_{RMS} = \sqrt{2q_e.I_{DC}.\Delta f}$$

where q_e is the electron charge, 1.6×10^{-19} C, I_{DC} is the DC current, and Δf is again the effective noise bandwidth.

Two common kinds of *pink* noise are:

Flicker: Also called $1/f$ noise, flicker noise is *not* completely understood, but it is thought to be due to defects in semiconductors causing electron velocity to vary. It decreases approximately as the reciprocal of frequency until several kilohertz, beyond which flicker noise power is nearly flat. Its amplitude is directly proportional to DC bias current.

Burst: Burst noise decreases approximately as $1/f^2$ so it is largely confined to low frequencies, and sounds like popcorn. hence its alternative name, **popcorn** noise.

The magnitudes of both kinds of pink noise, flicker and burst, depend sensitively on the the particular devices in which they arise, and are therefore difficult to predict with any precision.

17.2 Interference

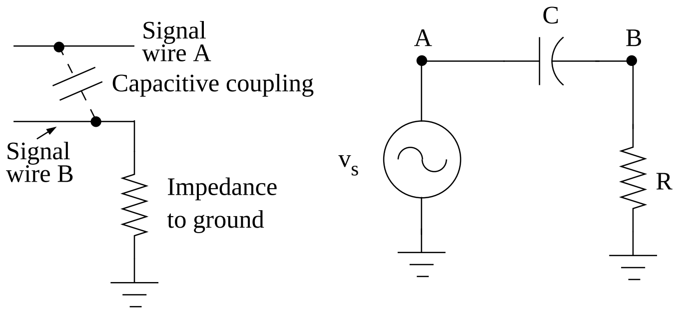
The term **interference** refers to all external signal disturbances, whether noise or other signals that are unfortunately combined with the desired signal. There are four major types of interference:

1. Electrically coupled.
2. Magnetically coupled.
3. Electromagnetic.
4. Common-mode.

17.2.1 Electrically Coupled Interference

This is **capacitive** (high-frequency) interference, due to another signal in a nearby conductor being capacitively coupled to the conductor carrying the desired signal. The mechanism is the electrostatic field produced between the two conductors which are at different voltages. See the following diagram.

Capacitively coupled interference from one wire to another.



(a) Physical arrangement. (b) Equivalent circuit.

The principal sources of capacitive interference are:

1. fluorescent lamps
2. unconnected power sockets
3. unconnected ceiling light sockets

All three are terminations of the mains power lines, so the characteristic, uneven, 50 Hz, periodic waveform is the most common form of electrically coupled interference.

Referring to the above figure, the RMS voltages at the two points A (the source of the interference) and B (where the interference occurs with the desired signal) are related by:

$$\frac{v_B}{v_A} = \frac{R}{\sqrt{R^2 + X_C^2}}$$

where R is the resistance of the path to ground in the signal wire B, and X_C is the capacitive reactance of the electrostatic coupling with the wire A that is the source of the interference. The capacitance C is difficult to estimate precisely unless we know exactly how the conductors are arranged, but for frequencies under 10 MHz and distances under 60 cm, the reactance X_C will be a few thousand ohms (a few kΩ), and will of course decrease with increasing frequency.

The above equation, simple though it is, tells us that capacitively coupled interference voltage will *increase* with increasing:

1. Capacitance between the source and the pickup circuit.
2. Frequency of the interfering voltage source.
3. Amplitude of the interfering voltage source - no surprise there!
4. Input impedance of the pickup circuit.

We don't have control over the frequency or amplitude of the mains power, which are fixed at 50 Hz and 230 V RMS. So to reduce its effect, we must decrease either the unwanted coupling capacitance, or the input impedance of the pickup circuit. Reducing the input impedance causes greater loading by our instruments, and therefore poorer circuit performance. So the best option is to reduce that pesky capacitance, by **shielding** the pickup circuit. We discuss shielding in greater detail later.

17.2.2 Magnetically Coupled Interference

Currents give rise to magnetic fields. So a changing current causes a changing magnetic field. In the presence of an inductor such as any length of wire, especially coils, this produces an interference voltage. Hence this is called **magnetically coupled** or **inductive** (low-impedance) interference.

Typical sources of inductive interference are:

1. Power transformers.
2. Power cords.
3. Large ground-loop currents.

Inductive coupling is inversely proportional to:

1. Frequency - so it is worst at low frequencies.
2. Distance - as expected.

At frequencies under 1 MHz and distances under 60 cm, the inductive coupling impedance may be several ohms.

Counter-measures include:

1. Low currents.
2. High impedances.
3. Large spacings between conductors.
4. Short conductors.
5. Elimination of the low-frequency response of the pickup circuit.

However, high impedances will increase capacitive interference! Both types of interference are reduced by greater separation between the noise source and pickup circuit. Proper shielding also helps, but it is more difficult to shield against inductive (magnetic) than capacitive (electric) interference. One help is the use of twisted pairs in power cords, as this significantly reduces the magnetic field surrounding the cord by reducing the area between the pair of wires inside the cord.

17.2.3 Electromagnetic Interference (EMI)

Time-varying currents, as in alternating current, produce propagating electromagnetic fields. EMI is caused principally by high-frequency sources, and therefore is RF ("radio frequency") radiation. RF signals are produced, among other sources, by:

1. Radio station transmitters.
2. Electric motors and generators.
3. Microwave ovens.
4. Remote-control garage-door openers.
5. Radar detectors and scanners.
6. Oscillator circuits in television and radio receivers.
7. Computers.

Electromagnetic interference has proportionate electric (capacitive) and magnetic (inductive) components. The upside of this is that to reduce EMI, it's sufficient to reduce either component, in particular the more easily countered electric component. Metal-wire mesh (see later) is the most common material for EMI shields.