Noises in Biomedical Instrumentation

Instrumental Noise: Noise is associated with each component of an instrument – i.e., with the source, the input transducer, signal processing elements and output transducer. Noise is a complex composite that usually cannot be fully characterized. Certain kinds of instrumental noise are recognizable, such as:

1. Thermal or Johnson noise
2. Shot noise
3. Flicker or 1/f noise
4. Offset and Drift
5. Environmental noise

Instrumental Noise

1. Thermal Noise or Johnson Noise:

Thermal noise is caused by the thermal agitation of electrons or other charge carriers. This originates mainly from the resistors in a circuit and arises from the fact that the mobile charge carriers in a resistor are in constant thermal motion.

Thus, at any one time the charge distribution over the resistor is not quite uniform. This causes a potential difference across the ends of the device. As the thermal motion proceeds, the potential fluctuates in a random manner about a mean of zero.

Instrumental Noise

The magnitude of thermal noise is given by

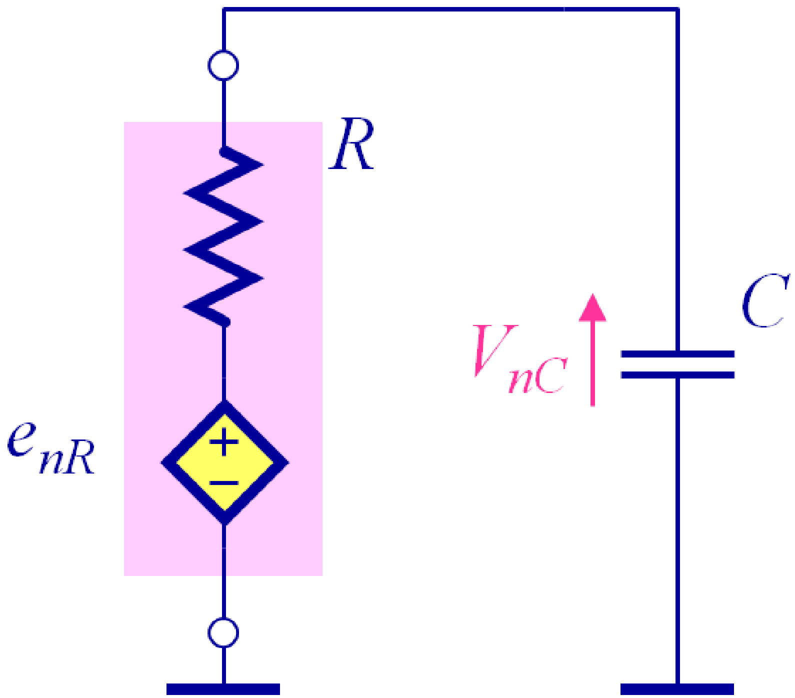
$$\bar{\nu}_{rms} = \sqrt{4kTR\Delta f}$$

where, ν_{rms} = root mean square noise, Δf = frequency band width (Hz), k = Boltzmann constant (1.38×10^{-23} J/K), T = temperature in Kelvin, R = resistance in ohms of the resistive element.

Instrumental Noise

Ideal capacitors and inductors do not generate any thermal noise. However, they *do accumulate* noise generated by other sources.

For example, the noise power at a capacitor that is connected to an arbitrary resistor value equals kT/C



$$V_{nC}^{\,2} = \frac{kT}{C}$$

Instrumental Noise

2. Shot Noise: Shot noise tends to predominate in the semiconductor components in a circuit, i.e. in the diodes and the transistors. It is actually a manifestation of the fact that an electric current is not a continuum but consists of discrete current carriers, i.e. electrons and 'holes'. Thus the commonly used analogy of a stream of flowing water to represent an electric current might more properly be replaced by a stream of grains of sand. It is then the 'grainy' nature of the flow that constitutes the shot noise.

Instrumental Noise

2. Shot Noise:

$$i_{rms} = \sqrt{2Ie\Delta f}$$

Where, i_{rms} = root-mean-square current fluctuation,

I = average direct current,

e = charge on the electron (1.60×10^{-19} C),

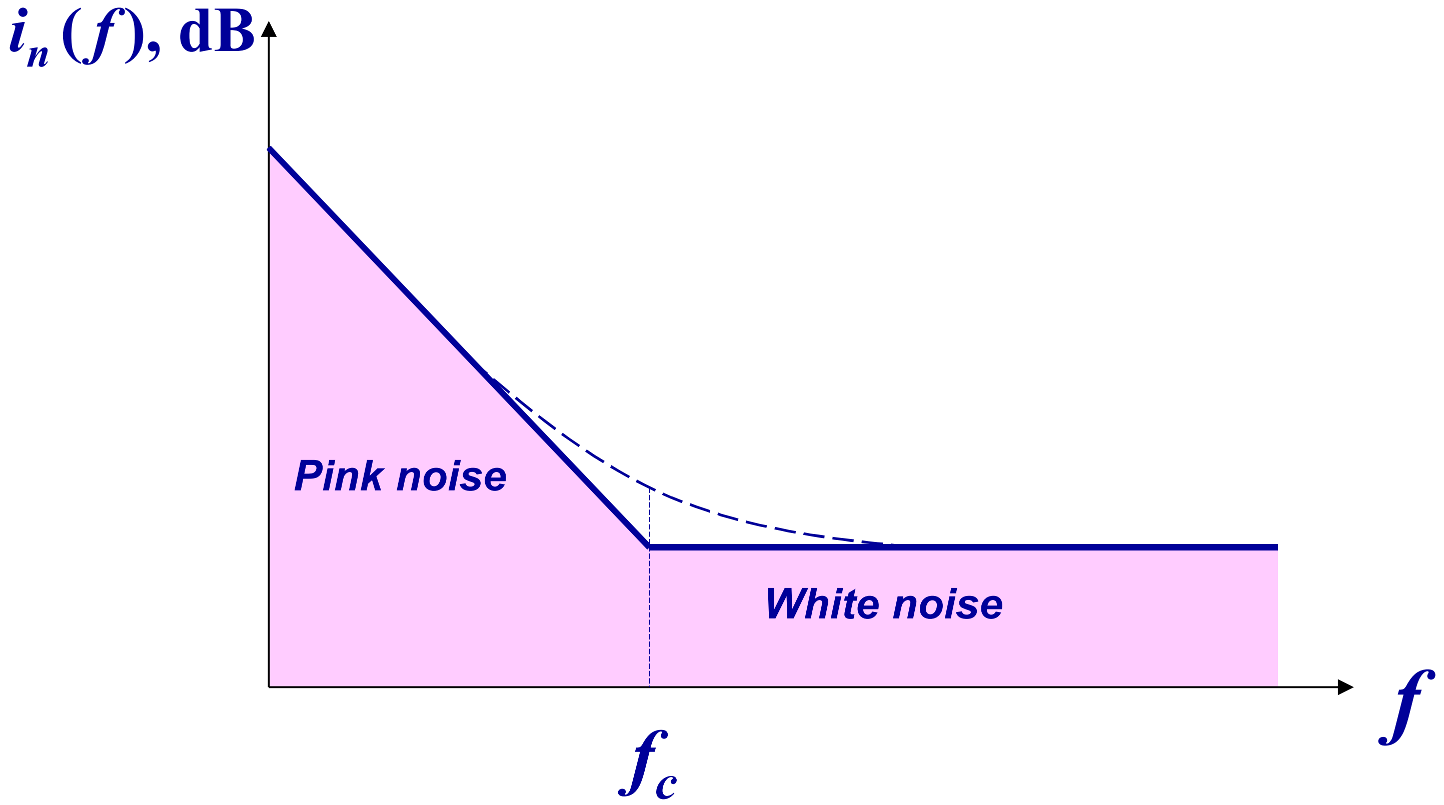
Δf = band width over which the noise is measured.

3. 1/f Noise or Flicker Noise or Pink noise: Thermal noise and shot noise are irreducible (ever present) forms of noise. They define the minimum noise level or the 'noise floor'. Many devices generate additional or excess noise.

In electrical and electronic devices, flicker noise occurs only when electric current is flowing.

In semiconductors, flicker noise usually arises due to traps, where the carriers that would normally constitute dc current flow are held for some time and then released.

3. 1/f Noise or Flicker Noise or Pink noise:



3. 1/f Noise or Flicker Noise or Pink noise:

An important parameter of $1/f$ noise is its corner frequency, f_c, where the power spectral density equals the white noise level. A typical value of f_c is 100 Hz to 1 kHz (MOSFET: 100 kHz).

Flicker noise can be reduced significantly by using wire-wound or metallic film resistors rather than the more common carbon composition type.

4. Offset and Drift:

Drift may be caused by variations in power supply or by temperature changes within the amplifier.

The remedy is stabilized power supply and to keep temperatures constant as far as possible. A much slower drift effect may be caused by the ageing of components within the amplifier.

5. Environmental Noise:

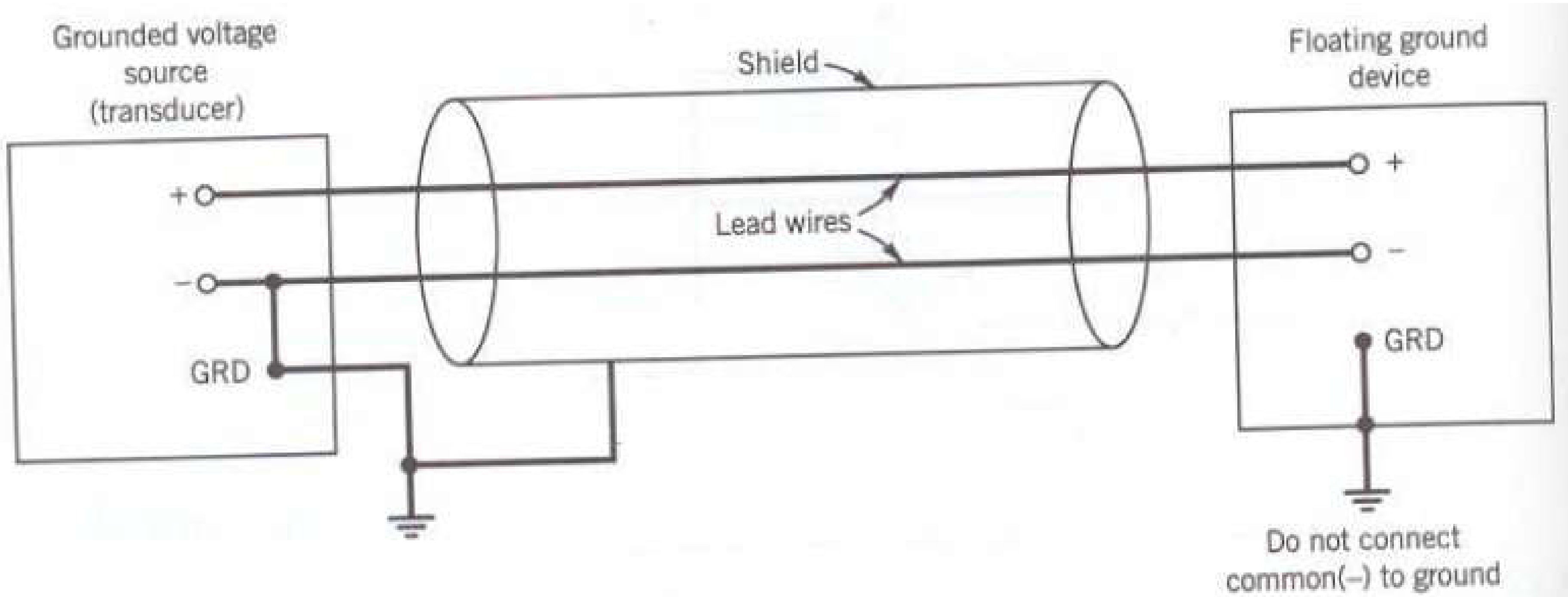
Environmental noise is a composite of different forms of noise that arise from the surroundings. Much environmental noise occurs because each conductor in an instrument is potentially an antenna capable of picking up electromagnetic radiation and converting it to an electrical signal.

Methods of Noise removal from Biomedical Signals

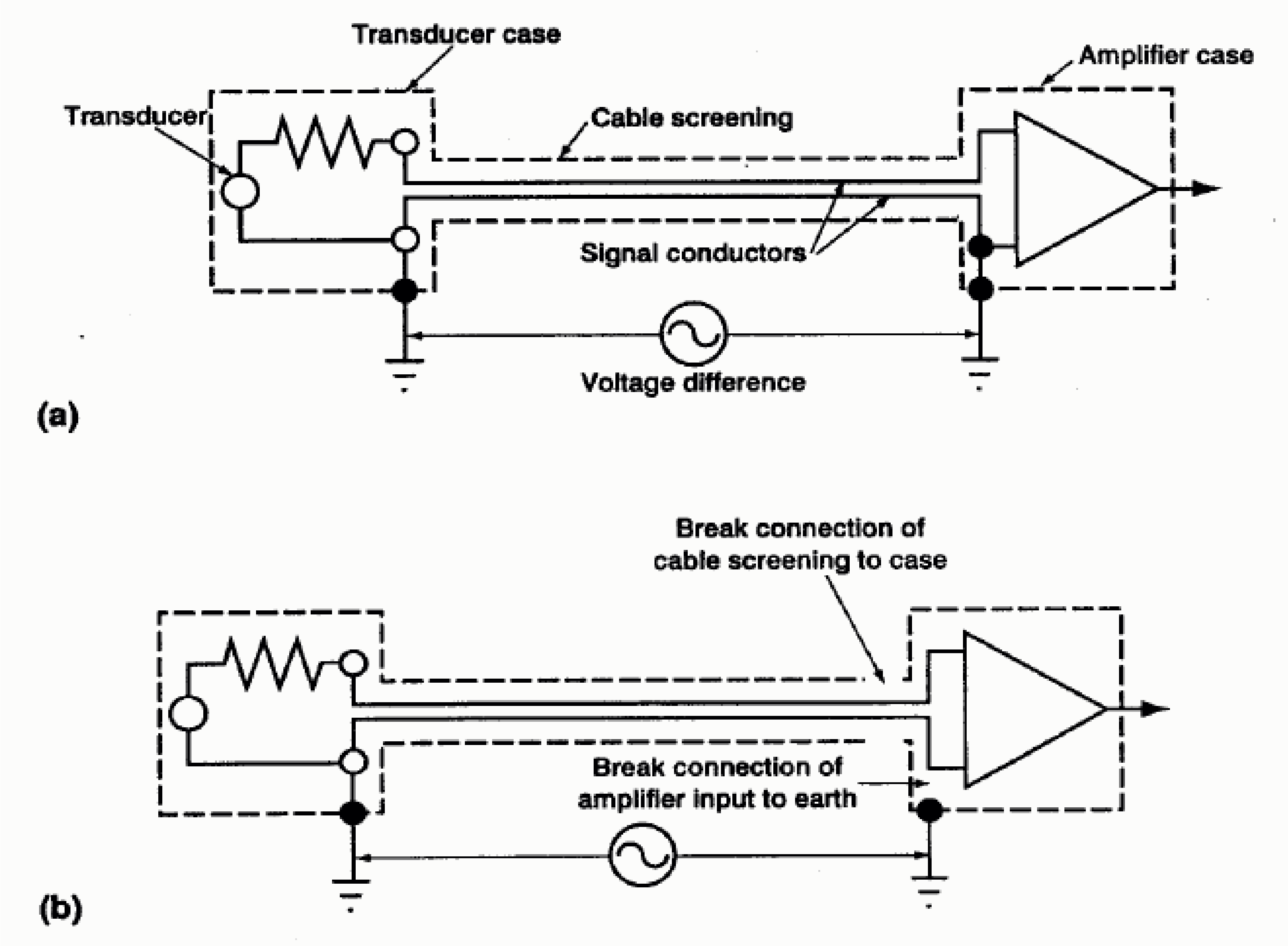
Hardware method:

1. Grounding and Shielding: Noise that arises from environmentally generated electromagnetic radiation can be substantially reduce by shielding, grounding and minimizing the length of conductors within the instrumental system.

Various Grounding and Shielding setups for noise removal



Connection in (a) will be prone to noise. (b) is preferable



2. Analog Filtering: By using low-pass and high-pass analog filters S/N ratio can be improved.

3. Modulation: In this process, low frequency or dc signal from transducers are often converted to a higher frequency, where 1/f noise is less troublesome. This process is called modulation. After amplification the modulated signal can be freed from amplifier 1/f noise by filtering with a high-pass filter, demodulation and filtering with a low-pass filter then produce an amplified dc signal suitable for output.

4. Signal chopping: In this case, the input signal is converted to a square-waveform by an electronic or mechanical chopper. This is the equivalent to modulation using a square wave Chopping can be performed either on the physical quantity to be measured or on the electrical signal from the transducer. Suitable for offset and 1/f noise removal.

5. Lock-in-Amplifiers: Lock-in-amplifiers permit the recovery of signals even when the S/N is unity or less. It requires a reference signal that has the same frequency and phase as the signal to be amplified. A lock-in amplifier is generally relatively free of noise because only those signals that are locked-in to the reference signal are amplified. All other frequencies are rejected by the system.

Software Method: Software methods are based upon various computer algorithms that permit extraction of signals from noisy data. Hardware convert the signal from analog to digital form which is then collected by computer equipped with a data acquisition module. Software programs are as follows:

1. Ensemble Averaging: In ensemble averaging, successive sets of data stored in memory as arrays are colleted and summed point by point. After the collection and summation are complete, the data are averaged by dividing the sum for each point by the number of scans performed. The signal-to-noise ratio is proportional to the square root of the number of data collected.

2. Boxcar Averaging: Boxcar averaging is a digital procedure for smoothing irregularities and enhancing the signal-to-noise ratio. It is assumed that the analog analytical signal varies only slowly with time and the average of a small number of adjacent points is a better measure of the signal than any of the individual points. In practice 2 to 50 points are averaged to generate a final point. This averaging is performed by a computer in real time, i.e., as the data is being collected.

3. Digital filtering (covered in DSP)