# Noise models for diodes and transistors

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- pn junctions and BJTs - shot noise, flicker noise, burst noise
- MOSFETs - flicker noise, thermal noise in strong inversion, shot noise in weak inversion, burst noise
- Shot noise occurs due to various reasons - random emission of carriers across a barrier, random tunneling of carriers, generation/recombination processes in bulk and depletion region, thermal fluctuations triggering a relaxation current through diffusion. The PSD of shot noise is proportional to the current
- Some controversy on origin of flicker noise - whether it occurs due to number (of carriers) or mobility fluctuations. Models are empirical models.
- Burst noise (or random telegraph signal) is seen as random "bursts" of noise in the time domain - occurs due to charging/discharging of a single defect

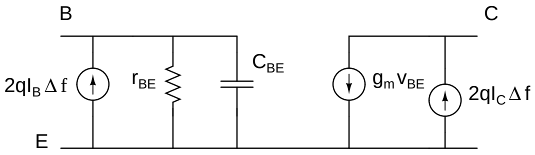
# Diodes

- Shot noise occurs because the minority carrier density in the bulk fluctuates due to thermal motion and generation/recombination of carriers. This triggers a relaxation current - the current flow is by diffusion
- The noise spectral density is given as

$$S_I(f) = 2q(I + 2I_s)$$

- A more accurate expression includes a frequency dependent term

# Bipolar Junction transistor




- Shot noise - mechanism is similar to diodes (narrow diodes)
- The spectral densities are given by

$$S_{I_E} = 2qI_E, \quad S_{I_B} = 2qI_B, \quad S_{I_C} = 2qI_C$$

- The three noise current sources are correlated

$$S_{CE} = -2qI_C \Rightarrow c_{CE} = -\sqrt{\alpha}$$

$$S_{BE} = -2qI_B \Rightarrow c_{BE} = -\sqrt{\frac{\alpha}{\beta}}$$

- The collector base correlation occurs due to charging and discharging of the diffusion capacitance

$$S_{CB} = -2qI_C \frac{j\omega\tau_t}{3} \Rightarrow c_{CB} = -\sqrt{\beta}\frac{j\omega\tau_t}{3}$$

where $\tau_t$ is the base transit time

## MOSFET - strong inversion

- Random thermal motion of carriers in the inversion layer
- Modelled as a voltage dependent nonlinear resistor
- The noise in the drain current is

$$i_d^2 = 4kT\frac{\mu}{L^2}|Q_{inv}|\Delta f$$

  where $Q_{inv}$ is the total inversion charge in the MOSFET
- In a simple model, ignoring channel length modulation,

$$Q_{inv} = \frac{2}{3}WLC_{ox}(V_{GS} - V_T)\frac{1+\alpha+\alpha^2}{1+\alpha}$$

  where

$$\alpha = 1 - \frac{V_{DS}}{V_{GS} - V_T}$$

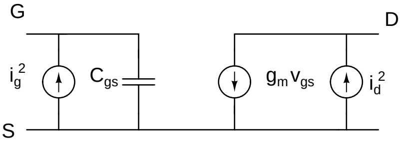
- More complex models take into account velocity saturation

## Induced gate noise

- Voltage fluctuations in the channel coupled to the gate through $C_g$
- Induced gate noise correlated to the drain noise
- A potential fluctuation at $v(x)$ causes a gate current $i_g$ given by

$$i_g = -j\omega W \int_o^L C_g(x) v(x) dx$$

# Long channel transistor in saturation




- For long channel devices in saturation $(V_{Dsat} = V_{GS} - V_T)$, the PSDs of the drain current and induced gate current are

$$S_{i_d} = 4kT\frac{2}{3}g_m, \qquad S_{i_g} = 4kT\frac{16}{135}\frac{\omega^2(WLC_{ox})^2}{g_m}$$

- The drain and gate noise are correlated and the cross spectral density is

$$S_{i_g i_d*} = 4kT\frac{1}{9}j\omega C_{ox}WL$$

- The correlation coefficient (coherence function) is therefore

$$c = \frac{S_{i_g i_d*}}{\sqrt{S_{i_d} S_{i_g}}} \approx 0.395j$$

# $1/f$ Noise

- Fluctuations in the curent due to trapping/detrapping by interfacial defects
- A simple model is

$$i_{df}^2 = \frac{Kg_m^2}{WLC_{ox}^2}\frac{1}{f}\Delta f$$

- Often just modelled as

$$i_{df}^2 = K'\frac{I_{DS}^a}{f}$$

  where $a$ is left as a parameter
- $K$ depends on device type and processing

# Other noise sources

- Thermal noise due to the distributed gate resistance ($R_g$)
- Thermal noise due to source and drain resistances $R_s$ and $R_d$
- Shot noise due to gate tunneling current and junction diodes
- Noise due to hot electrons (in submicron devices)
- Substrate noise
- RTS noise

# References


1. A.van der ziel "Noise in solid state devices and circuits"
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4. A.Van der ziel, "Unified presentation of $1/f$ noise in electronic devices: Fundamental $1/f$ noise sources", Proc. IEEE, vol.76, no.3, Mar 1988