



UNIVERSITÉ DE
SHERBROOKE

Comment se Propage un Signal Électro-Magnétique?

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A large iceberg floating in the ocean. The tip of the iceberg is visible above the water surface, while the much larger, jagged base is submerged below. The water is a deep blue, and the sky is a clear, lighter blue.

Level 3: Impedance & Reflection [20min - 1h10]

A photograph of an iceberg floating in the ocean. The tip of the iceberg is visible above the water surface, while a much larger, jagged mass of ice is submerged below the surface. The water is a deep blue, and the sky is a clear, lighter blue.

Level 3: Impedance & Reflection [20min - 1h10]

- ✗ Type of source
- ✗ High/Low Impedance
- ✗ GPIO output circuit

An iceberg floating in the ocean. The tip of the iceberg is visible above the water surface, while the much larger, submerged part is visible below the surface. The water is dark blue, and the sky is a clear, bright blue.

Level 3: Impedance & Reflection [20min - 1h10]

Electric Permittivity [F/m]:

$$\varepsilon = \varepsilon_r \varepsilon_0$$

Nous avons initialement considéré ces valeurs comme étant des nombre réel \mathbb{R} .

Magnetic Permeability [H/m]:

$$\mu = \mu_r \mu_0$$

Cela fonctionne très bien pour définir des matériaux **sans pertes**.

Refractive Index:

$$n = \frac{\sqrt{\varepsilon \mu}}{\sqrt{\varepsilon_0 \mu_0}} = \sqrt{\varepsilon_r \mu_r}$$

Par contre, dans la vraie vie, ce sont des nombres complexes \mathbb{C} . Cela permet de définir des matériaux **avec pertes**

Indice de Refraction Complexe:

$$\tilde{n} = n + jk$$

Permittivité Complexe:

$$\epsilon = \epsilon_1 + j\epsilon_2 = (n + jk)^2$$

$$\epsilon_1 = n^2 - k^2$$

$$\epsilon_2 = 2nk$$

Indice de Refraction:

$$n = \sqrt{\frac{\sqrt{\epsilon_1^2 + \epsilon_2^2} + \epsilon_1}{2}}$$

Coefficient d'Extinction:

$$k = \sqrt{\frac{\sqrt{\epsilon_1^2 + \epsilon_2^2} - \epsilon_1}{2}}$$

mettre graphique sinusoidale ammortie

$$T = e^{-kl} \quad (1)$$

a valider

A photograph of an iceberg floating in the ocean. The visible tip of the iceberg is white and jagged, while the much larger, submerged portion is a deep blue color, illustrating the concept of hidden complexity or depth. A dark green horizontal bar is overlaid across the middle of the image, containing the title text.

Level 3: Impedance & Reflection [20min - 1h10]

- ✗ PPPPP2
- ✗ Impedance dans le plan complexe
- ✗ Rappel qu'on ignore la conductance G .
- ✗ Propagation Constant (p.56)

- ✗ L'Électricité prend le chemin avec la plus petite **Resistance**
- ✓ L'Électricité prend le chemin avec la plus petite **Impedance**

A photograph of an iceberg floating in the ocean. The tip of the iceberg is visible above the water surface, while a much larger, jagged mass of ice is submerged below the surface. The water is a deep blue, and the sky is a clear, lighter blue.

Level 3: Impedance & Reflection [20min - 1h10]

- ✗ Bounce Diagram
- ✗ Impedance Mismatch
- ✗ Item 3

A photograph of an iceberg floating in the ocean. The tip of the iceberg is visible above the water surface, while a much larger, jagged mass of ice is submerged below the surface. The water is a deep blue, and the sky is a clear, lighter blue.

Level 3: Impedance & Reflection [20min - 1h10]

- ✗ Equation de base
- ✗ Pertes en dB (exponential decay)

A photograph of an iceberg floating in the ocean. The visible tip of the iceberg is small and white against a clear blue sky. The vast majority of the iceberg is submerged underwater, appearing as a large, jagged, and textured mass of white and light blue ice. The water is a deep, dark blue. A semi-transparent green rectangular box is overlaid on the center of the image, containing white text.

Level 4: Noise [27min - 1h37]

A large iceberg floating in the ocean, with a significant portion submerged below the water line. The water is a deep blue, and the sky is a clear, lighter blue. The submerged part of the iceberg is much larger and more complex in shape than the visible tip.

Level 4: Noise [27min - 1h37]

- ✗ Pourquoi c'est important
- ✗ Analogie des dB avec le stock market
- ✗ Item 3

Signal Power in dB

$$P_{Signal|dB} = 10 \log \frac{P_{Signal|W}}{1W} \quad (2)$$

Signal Power in dBm

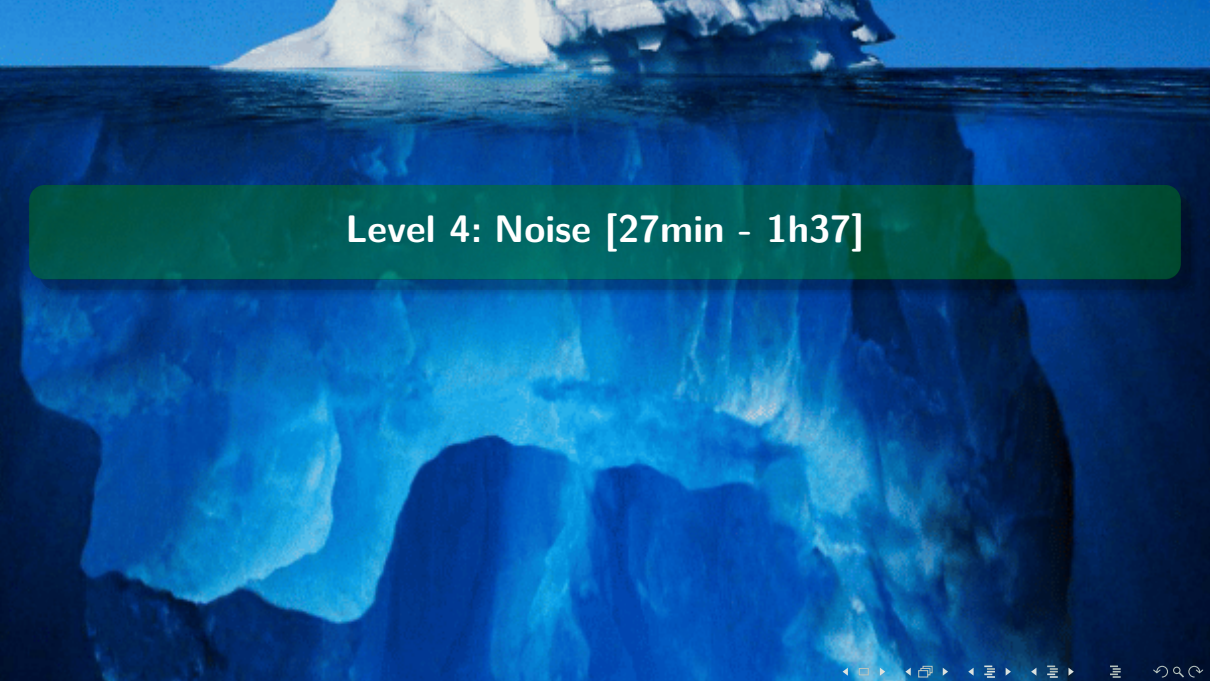
$$P_{Signal|dBm} = 10 \log \frac{P_{Signal|mW}}{1mW} \quad (3)$$

Voltage Gain

$$A_{V|dB} = 20 \log \frac{V_{out}}{V_{in}} \quad \Longleftrightarrow \quad \frac{V_{out}}{V_{in}} = 10^{\frac{A_V}{20}} \quad (4)$$

Power Gain

$$A_{V|dB} = 10 \log \frac{P_{out}}{P_{in}} \quad \Longleftrightarrow \quad \frac{P_{out}}{P_{in}} = 10^{\frac{A_P}{10}} \quad (5)$$

A large iceberg floating in the ocean, with a significant portion submerged below the water line. The water is a deep blue, and the sky is a clear, lighter blue. The submerged part of the iceberg is much larger and more jagged than the visible tip.

Level 4: Noise [27min - 1h37]

- ✗ Random Noise Source
- ✗ Noise Power
- ✗ Source of noise in a circuit

- ✗ Thermal Noise
- ✗ Environmental Noise
- ✗ Flicker Noise

Johnson-Nyquist Noise Equation:

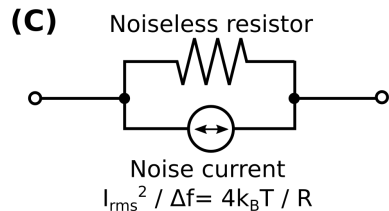
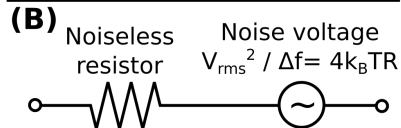
$$V_{rms} = \sqrt{4k_B T R \Delta f} \quad (6)$$

$k_b = 1.38 \times 10^{-23}$: Boltzmann Constant [J]

T : Temperature [K]

Δf : Frequency Range

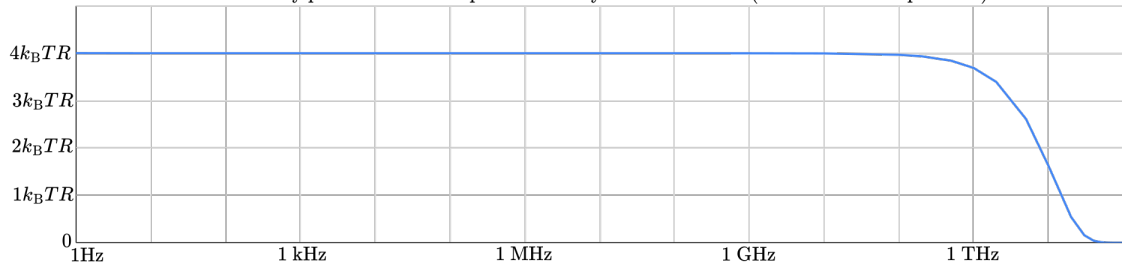
R : Resistance [Ohm]

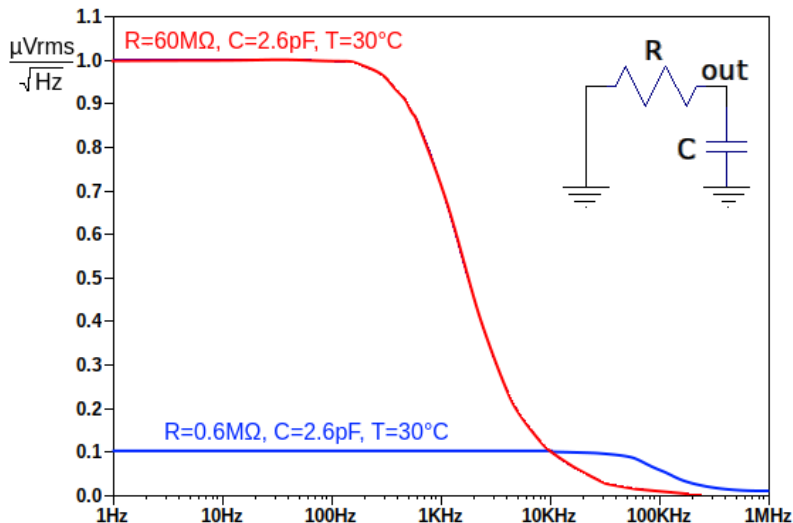


Valeurs pour 300k:

$$V_{rms} = 0.13 \cdot \sqrt{R\Delta f} \quad [nV] \quad (7)$$

Johnson-Nyquist noise Power Spectral Density of Ideal Resistor (around room temperature)







Bruit Condensateur:






$$V_{rms} = \sqrt{\frac{k_B T}{C}} \quad (8)$$

Bruit Inducteur:

$$\overline{I_n} = \sqrt{\frac{k_B T}{L}} \quad (9)$$

Table 1: Niveau de bruit thermique pour différentes applications (wiki)

Source	Bandwidth	Noise Power (300K)
Radio FM	10 kHz	-134 dBm
Bluetooth	1 MHz	-114 dBm
GPS	2 MHz	-111 dBm
WLAN 802.11	20 MHz	-101 dBm
WLAN 802.11n	40 MHz	-98 dBm
WLAN 802.11ac	80 MHz	-95 dBm
WLAN 802.11ac	160 MHz	-92 dBm

-  **Atmosphériques:** Éclairs, Effets Corona, etc...
-  **Industriel:** Lignes HV, Lampes Fluorescentes, etc...
-  **Solaire:** Vents solaires
-  **Cosmique:** Effets collectif des étoiles (8MHz-1.5GHz), CMB, Quasar, Pulsar, Chaos Gods
-  **Psychologique:** Toi qui fait pas tes lectures

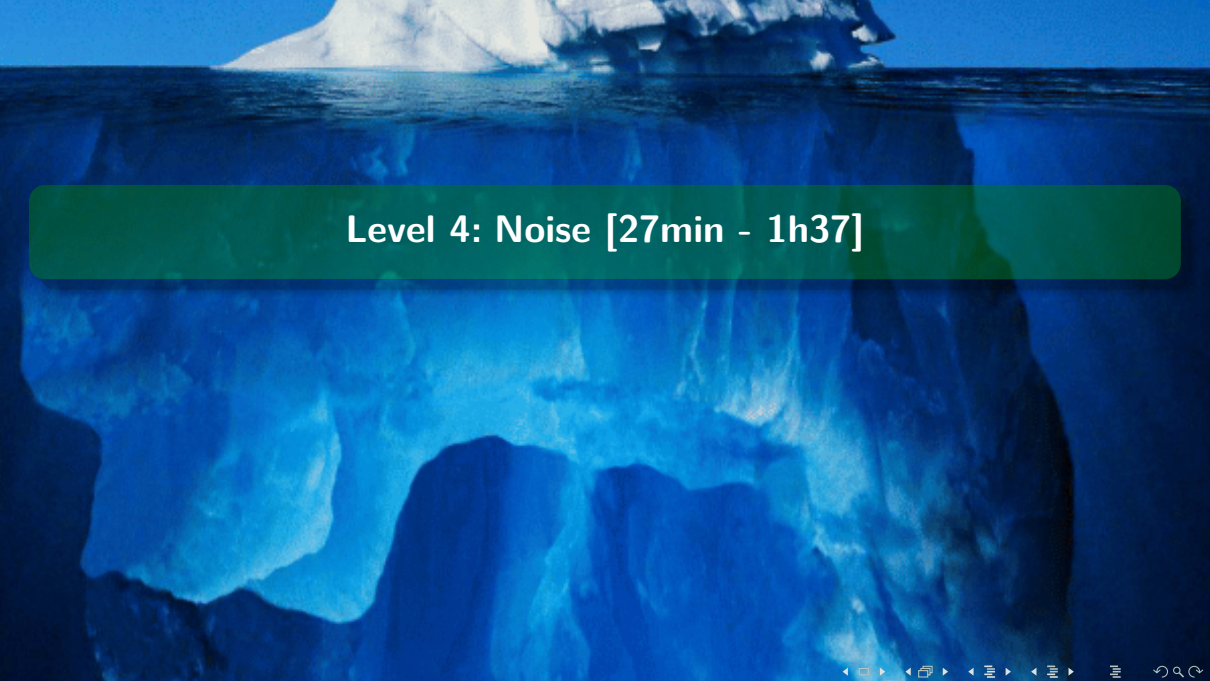
A large iceberg floats in a deep blue ocean under a clear sky. The visible tip of the iceberg is small, while the massive, jagged submerged portion is visible below the water line, illustrating the concept of the 'tip of the iceberg'.

Level 4: Noise [27min - 1h37]

- ✗ Frequency dependant noise power
- ✗ Demo avec type de bruit (red, white, brown, etc..)

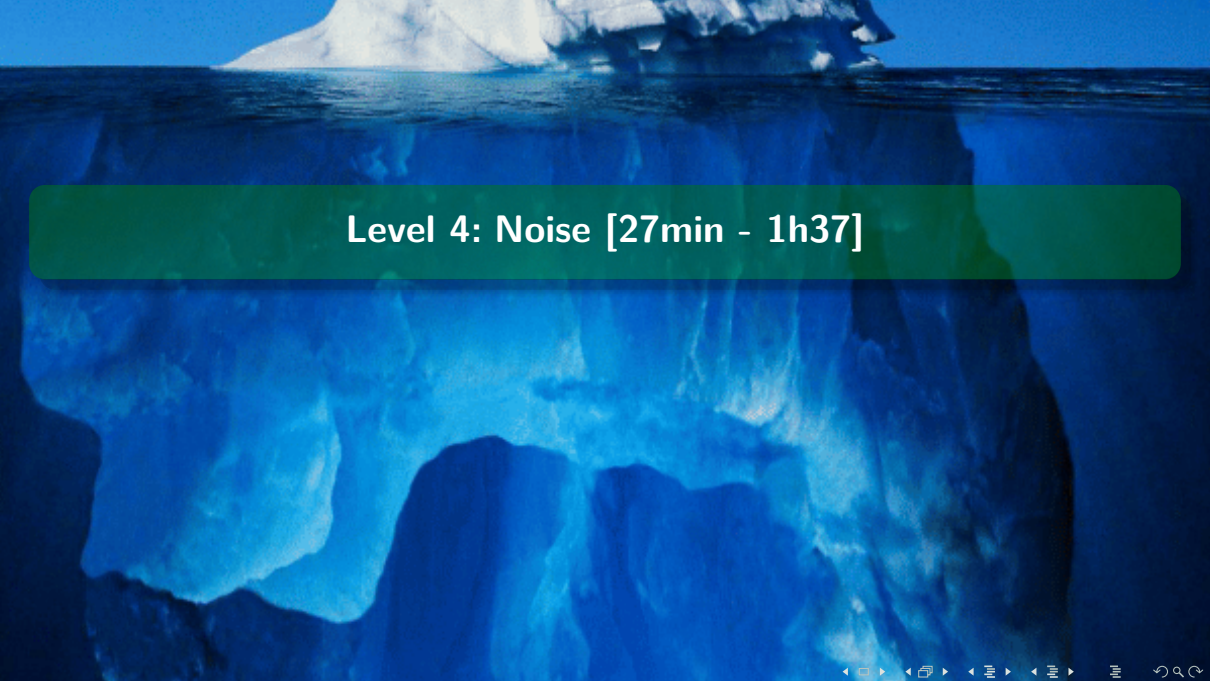
$$P_n = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T n^2(t) dt \quad (10)$$

$$\int_0^\infty S_x(f) df = \lim_{T \rightarrow \infty} \frac{1}{T} \int_0^T x^2(t) dt \quad (11)$$

A large iceberg floating in the ocean, with a significant portion submerged below the water line. The water is a deep blue, and the sky is a clear, lighter blue. The submerged part of the iceberg is much larger and more jagged than the visible tip.

Level 4: Noise [27min - 1h37]

- ✗ Gauss representation in frequency domain of a sine wave
- ✗ Sinc function
- ✗ Item 3

A large iceberg floating in the ocean, with a significant portion submerged below the water line. The water is a deep blue, and the sky is a clear, lighter blue. The submerged part of the iceberg is much larger and more jagged than the visible part above water.

Level 4: Noise [27min - 1h37]



- ✗ Why it matters
- ✗ How can you tell the SNR you need
- ✗ Shannon-Hartley Theorem
- ✗ Application: DAC,ADC
- ✗ Application: Example for Voyager 1 Detection Link



$$SNR = \frac{P_{\text{Signal}|W}}{P_{\text{Noise}|W}} = P_{\text{Signal}|dB} - P_{\text{Noise}|dB} \quad (12)$$

$$C = BW \cdot \log_2 \left(1 + \frac{P_{\text{Signal}|W}}{P_{\text{Noise}|W}} \right) \quad (13)$$



C: Canal Capacity [Bit/s]



BW: Canal Bandwidth [Hz]



Mettre tableau avec resolution et SNR

A large iceberg floats in a deep blue ocean under a clear sky. The visible tip of the iceberg is white and jagged, while the massive, submerged portion is a deep, translucent blue, revealing internal textures and air pockets. A dark green semi-transparent banner is centered horizontally across the middle of the image.

Level 4: Noise [27min - 1h37]

- ✗ Item 1
- ✗ Item 2
- ✗ Item 3

A large iceberg floats in a deep blue ocean under a clear sky. The visible tip of the iceberg is white and jagged, while the massive, submerged portion is a deep, translucent blue, revealing internal textures and air pockets. A dark green horizontal bar is centered across the middle of the image.

Level 4: Noise [27min - 1h37]

- ✗ Item 1
- ✗ Item 2
- ✗ Item 3



Level 5: Crosstalk & Coupling [18min - 1h55]



- ✗ Item 1
- ✗ Item 2
- ✗ Item 3

Level 5: Crosstalk & Coupling [18min - 1h55]



✗ Impedance du vide

✗

Level 5: Crosstalk & Coupling [18min - 1h55]

- ✗ Radiation Pattern
- ✗ Radiation Lense

Level 5: Crosstalk & Coupling [18min - 1h55]

- ✗ Twisted Pairs
- ✗ Do Differential Pairs need GND?

Level 5: Crosstalk & Coupling [18min - 1h55]

- ✗ Item 1
- ✗ Item 2
- ✗ Item 3

Level 5: Crosstalk & Coupling [18min - 1h55]

- ✗ Item 1
- ✗ Item 2
- ✗ Item 3



Merci!

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