TSEK02: Radio Electronics Lecture 1b: Basic Definitions

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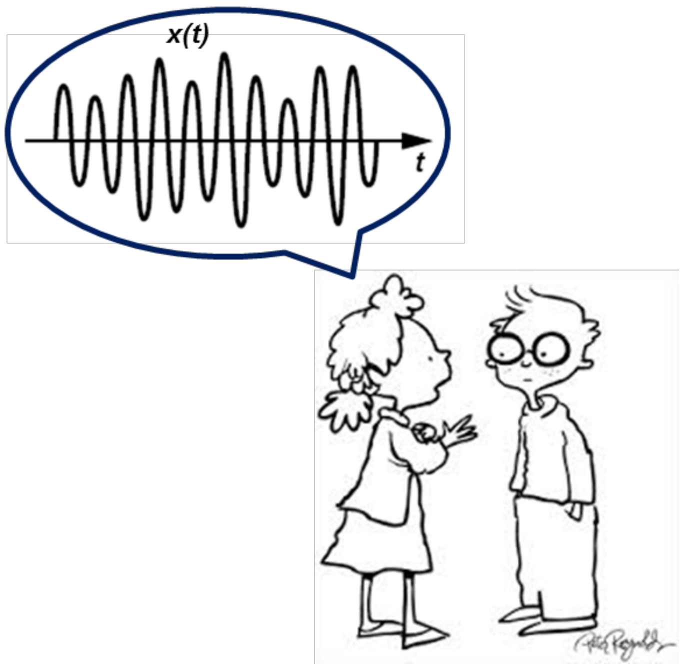
Basic Definitions

- Parts from Chapter 2, but mostly own material.

- Time and Frequency
- dB conversion
- Power and dBm
- Filter Basics

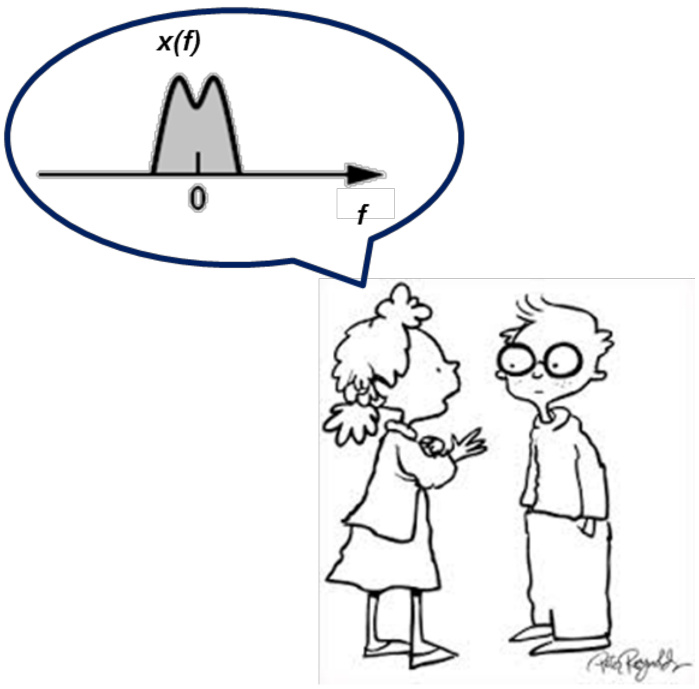
Time Domain

- The real world happens in the time domain!
- The independent variable is time, denoted by ”t”



Frequency Domain

- Signals may be represented by frequency components
- Independent variable is frequency ”f”



What is the unit of frequency?

Time domain vs. Frequency domain

Questions:

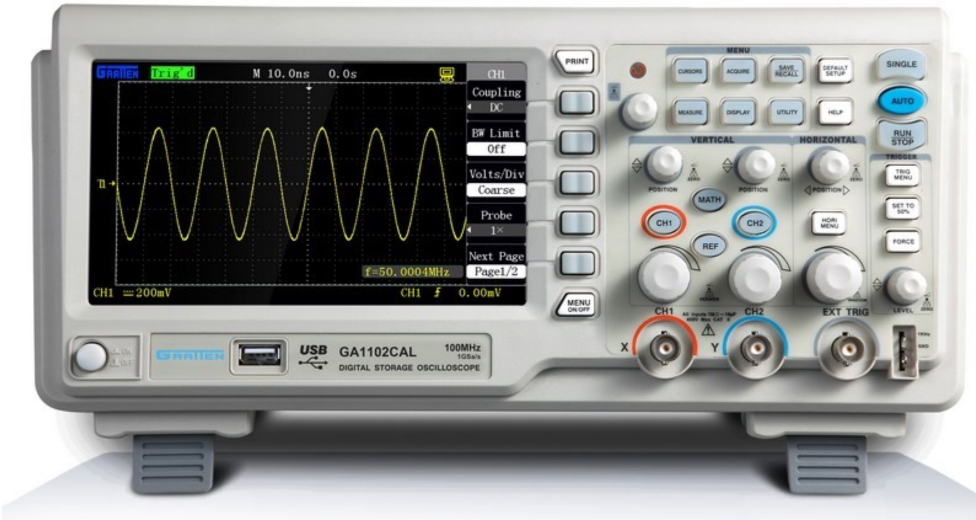
What instrument should you use for measuring the signal in the time domain or the frequency domain?

Time domain vs. Frequency domain

Questions:

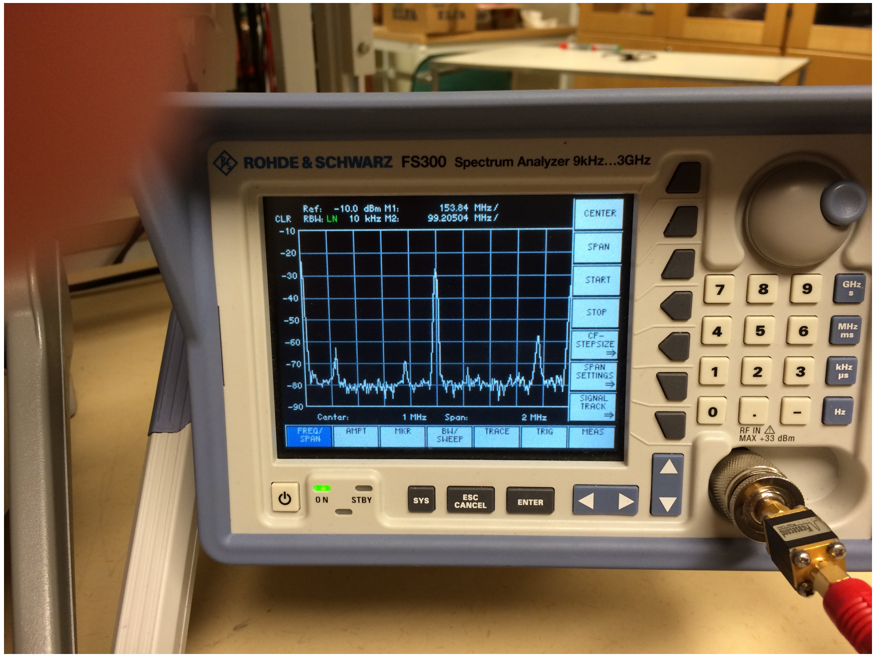
What instrument should you use for measuring the signal in the time domain or the frequency domain?

a) Oscilloscope time domain
b) Spectrum Analyzer frequency domain



Oscilloscope: time domain

Spectrum analyzer: frequency domain



Time domain vs. Frequency domain

- The two representations are related through <u>Fourier transformation</u> and both contain the same information

$$\mathbf{x(t)} \xleftrightarrow{\text{Fourier}} \mathbf{X(f)}$$

- Remember that by changing the signal in one domain, its representation in the other domain changes as well

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Joseph Fourier

From Wikipedia, the free encyclopedia

For the French socialist philosopher, see Charles Fourier.

Jean-Baptiste Joseph Fourier (/ˈfʊəri.eɪ, -iər/;[1] French: [fuʁje]; 21 March 1768 – 16 May 1830) was a French mathematician and physicist born in Auxerre and best known for initiating the investigation of Fourier series and their applications to problems of heat transfer and vibrations. The Fourier transform and Fourier's law are also named in his honour. Fourier is also generally credited with the discovery of the greenhouse effect.[2]

Joseph Fourier

Jean-Baptiste Joseph Fourier

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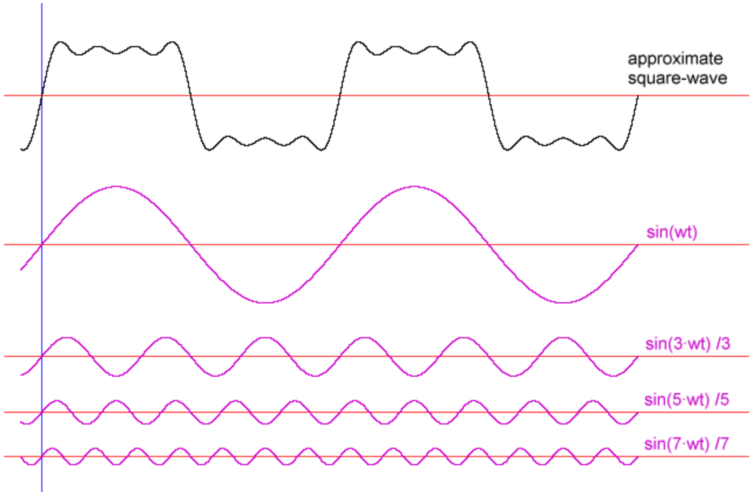
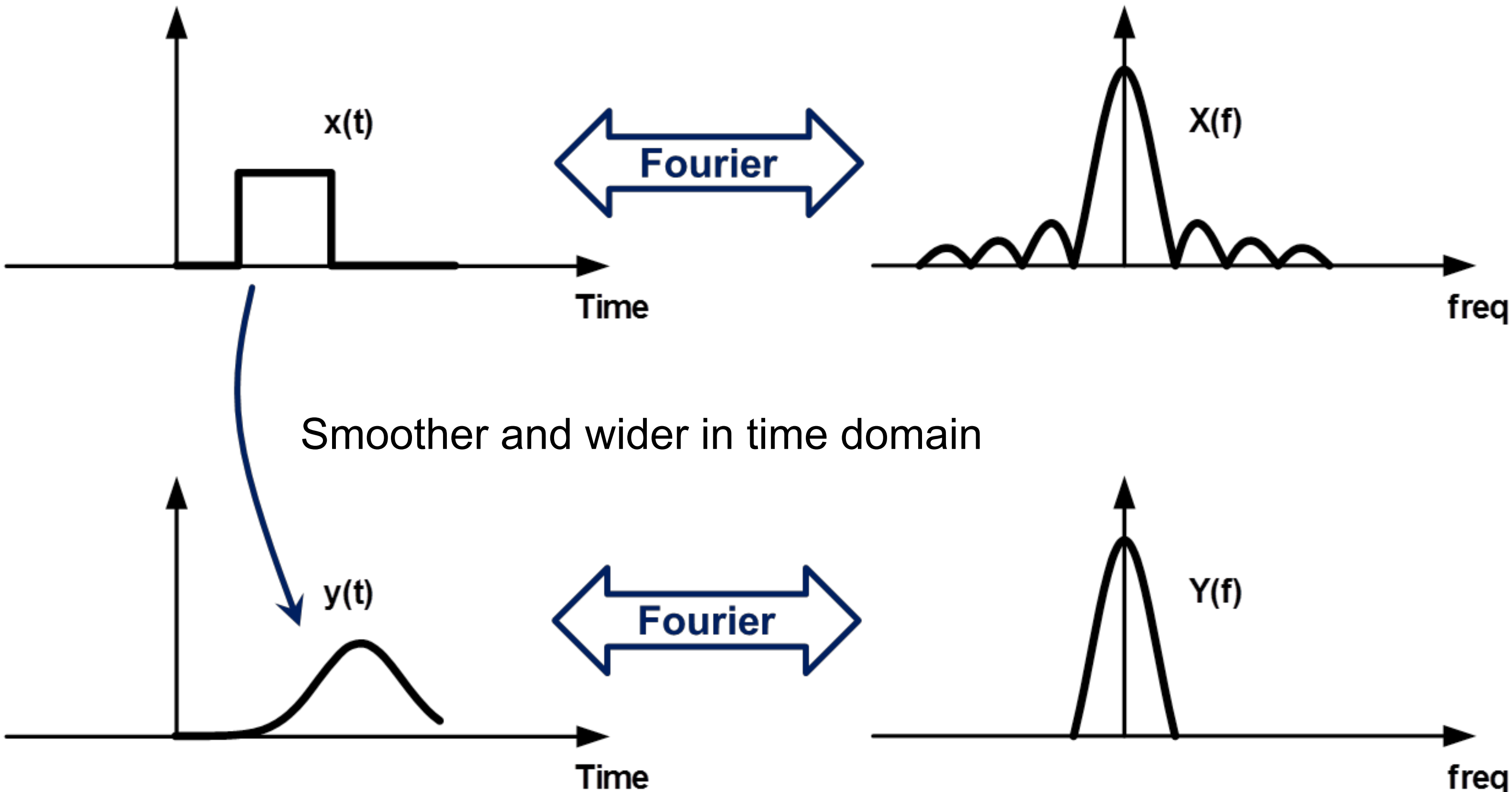
Square wave and its harmonics

- Ideal square waves consist of odd harmonics. Using Fourier expansion with cycle frequency f over time t, an ideal square wave with an amplitude of 1 can be represented as an infinite sum of sinusoidal waves:

$$x(t) = \frac{4}{\pi} \sum_{k=1}^{\infty} \frac{\sin(2\pi(2k-1)ft)}{2k-1}$$
$$= \frac{4}{\pi} \left(\sin(2\pi ft) + \frac{1}{3}\sin(6\pi ft) + \frac{1}{5}\sin(10\pi ft) + \cdots \right).$$

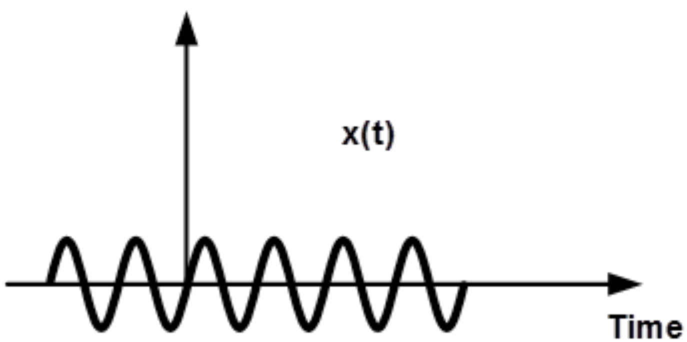


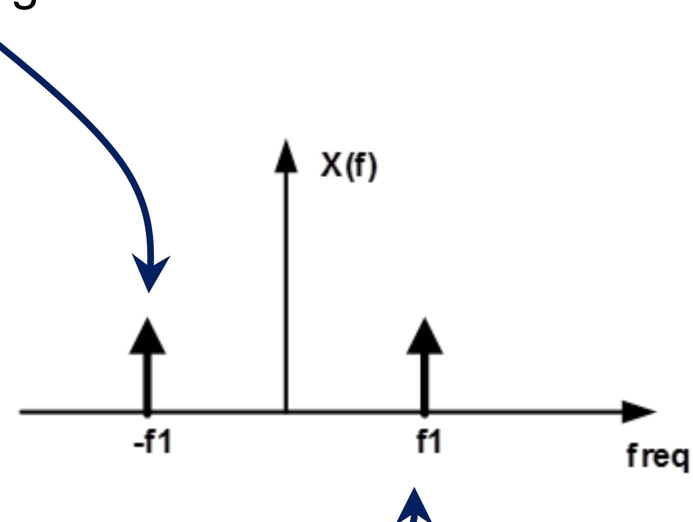
Example – effect of filtering



Negative Frequency

All real signals have this negative frequency components as well. It is called the image.





A sinusoidal signal is often called a single-tone because its frequency domain representation contains only one frequency

Basic Definitions

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dB (deci Bell)

- In order to make calculations and comparisons easier, RF system designers commonly use logarithmic scale

$$\log(1/x) = -\log x$$

$$\log(x \times y) = \log x + \log y$$

$$(y \times x)_{dB} = 10 \log(x^y)$$

- dB is logarithm base-10 and times 10

$$dB = 10 \log_{10}(X)$$

- Calculations become easier if you can quickly convert any number into its logarithm!

dB Calculations

Three important dB-numbers you have to remember

$$(10)_{dB} = 10 \log_{10} 10$$

10 dB is the same as 10 times

$$(0)_{dB} = 10 \log_{10} 1$$

0 dB is the same as the same

$$(3)_{dB} = 10 \log_{10} 2$$

3 dB is the same as 2 times

$(0)_{dB} = 10 \log_{10} 1$

$(1)_{dB} = 10 \log_{10} 1.25$

$(2)_{dB} = 10 \log_{10} \pi/2\ (1.57)$

$(3)_{dB} = 10 \log_{10} 2$

$(4)_{dB} = 10 \log_{10} 2.5$

$(5)_{dB} = 10 \log_{10} \pi\ (3.14)$

$(6)_{dB} = 10 \log_{10} 4$

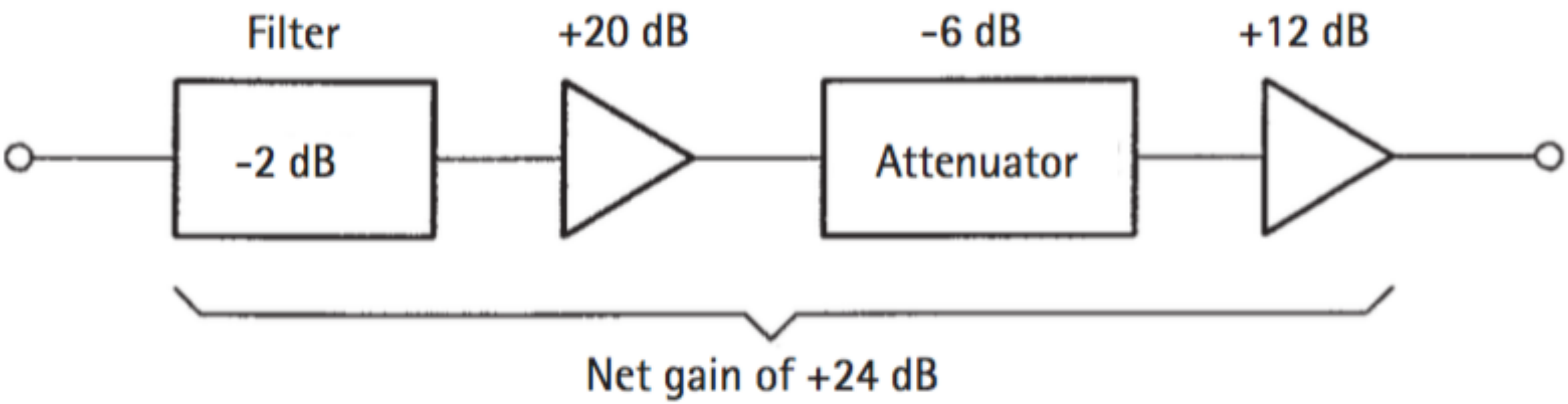
$(7)_{dB} = 10 \log_{10} 5$

$(8)_{dB} = 10 \log_{10} 2\pi\ (6.28)$

$(9)_{dB} = 10 \log_{10} 8$

$(10)_{dB} = 10 \log_{10} 10$

dB Calculations: example



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Alexander Graham Bell

From Wikipedia, the free encyclopedia

Alexander Graham Bell (March 3, 1847 – August 2, 1922)[4] was a Scottish-born[N 3] scientist, inventor, engineer and innovator who is credited with patenting the first practical telephone.[7]

Bell's father, grandfather, and brother had all been associated with work on elocution and speech, and both his mother and wife were deaf, profoundly influencing Bell's life's work.[8] His research on hearing and speech further led him to experiment with hearing devices which eventually culminated in Bell being awarded the first U.S. patent for the telephone in 1876.[N 4] Bell considered his most famous invention an intrusion on his real work as a scientist and refused to have a telephone in his study.[9][N 5]

Many other inventions marked Bell's later life, including groundbreaking work in optical telecommunications, hydrofoils and aeronautics. In 1888, Bell became one of the founding members of the National Geographic Society.[11]

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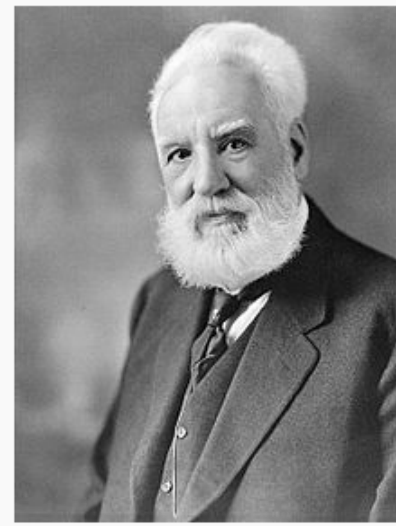
Alexander Graham Bell



Portrait photo taken between 1914–19.

Basic Definitions

- Time and Frequency
- dB conversion
- Power and dBm
- Filter Basics

Why Power?

- It is very difficult to accurately measure voltage or current signals at high frequencies.

- Real signals are random in nature. So it is a lot more useful to record the average and standard deviation instead of large data base of instantaneous amplitudes.

Power

- Measuring power is relatively easy, even at extremely high frequencies
- It can be done by dissipating the signal in a resistor and measuring the temperature
  - power conservation law
- We need to agree on a resistor value!
  - How about 50 Ohm?

Why 50 Ohm?

- Lloyd Espenscheid and Herman Affel, working for Bell Labs in 1929.
- They were going to send RF signals (4 MHz) for hundred of miles carrying a thousand telephone calls. They needed a cable that would carry <u>high voltage</u> and <u>high power</u>. In the graph, you can see the ideal rating for each. For high voltage, the perfect impedance is 60 ohms. For high power, the perfect impedance is 30 ohms.
- This means, clearly, that there is <u>NO perfect impedance</u> to do both. What they ended up with was a compromise number, and that number was 50 ohms.

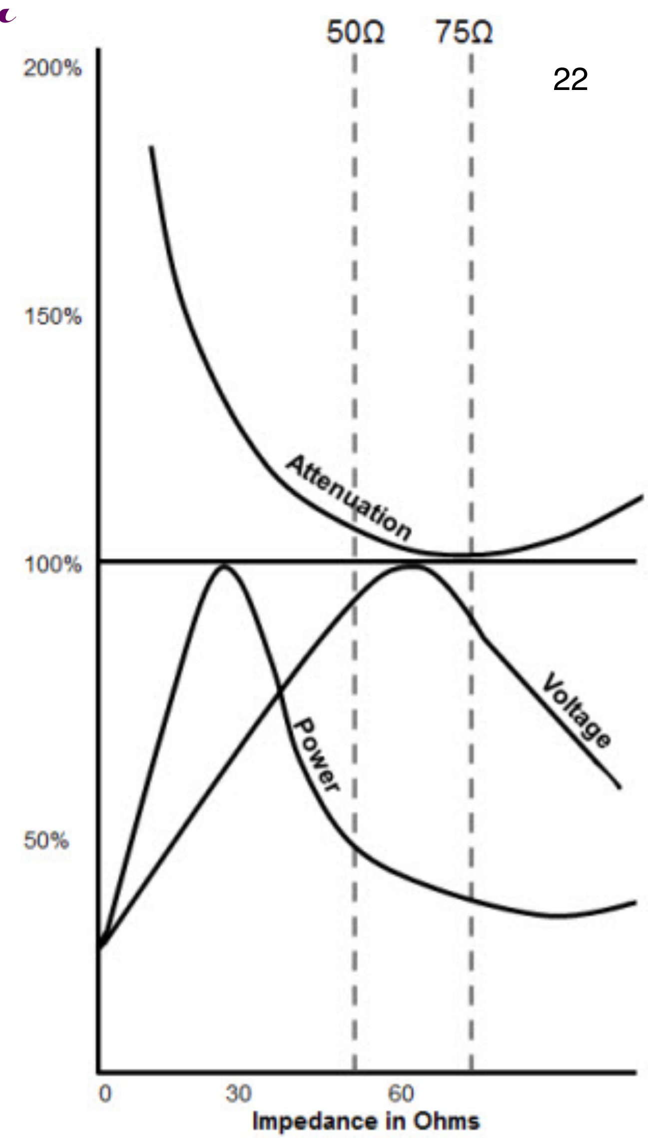


Figure 2-8 Coax impedance and loss
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Power in dBm

- Due to simplicity in calculations, we like to express power in logarithm scale!
- Power is not a ratio, so how can we do this?

- Calculate the ratio of the power to 1 mW and express that in dB! We call this dBm.

- 0 dBm = 1 mW.
- 1 W = X dBm?

$$P_{sig}\big|_{\mathrm{dBm}} = 10\log\left(\frac{P_{sig}}{1\ \mathrm{mW}}\right)$$

Power in dBm

Table 1.1
Sample Values of Decibels Referred to Milliwatts

Power	10 μW	100 μW	1 mW	10 mW	100 mW
dBm	–20	–10	0	+10	+20

24 dBm	251 mW	Maximal output from a UMTS/3G mobile phone (Power class 3 mobiles) 1,880–1,900 MHz DECT (250 mW per 1,728 kHz channel). EIRP for wireless LAN IEEE 802.11a (20 MHz-wide (5,180–5,320 MHz) or U-NII-2 & -W ranges (5,250–5,350 MHz & 5,470–5,725 MHz respectively). The former is
23 dBm	200 mW	EIRP for IEEE 802.11n wireless LAN 40 MHz-wide (5 mW/MHz) channels in 5 GHz subband 4 (5,735–5,835 M 5,725 MHz, EU only). Also applies to 20 MHz-wide (10 mW/MHz) IEEE 802.11a wireless LAN in 5 GHz subban 802.11h-compliant (otherwise only 3 mW/MHz → 60 mW when unable to dynamically adjust transmission powe transmitter also cannot dynamically select frequency).
22 dBm	158 mW	
21 dBm	125 mW	Maximal output from a UMTS/3G mobile phone (Power class 4 mobiles)
20 dBm	100 mW	EIRP for IEEE 802.11b/g wireless LAN 20 MHz-wide channels in the 2.4 GHz Wi-Fi/ISM band (5 mW/MHz). Bluetooth Class 1 radio. Maximal output power from unlicensed AM transmitter per U.S. FCC rules 15.219[5]

Wikipedia

dBu and dBW

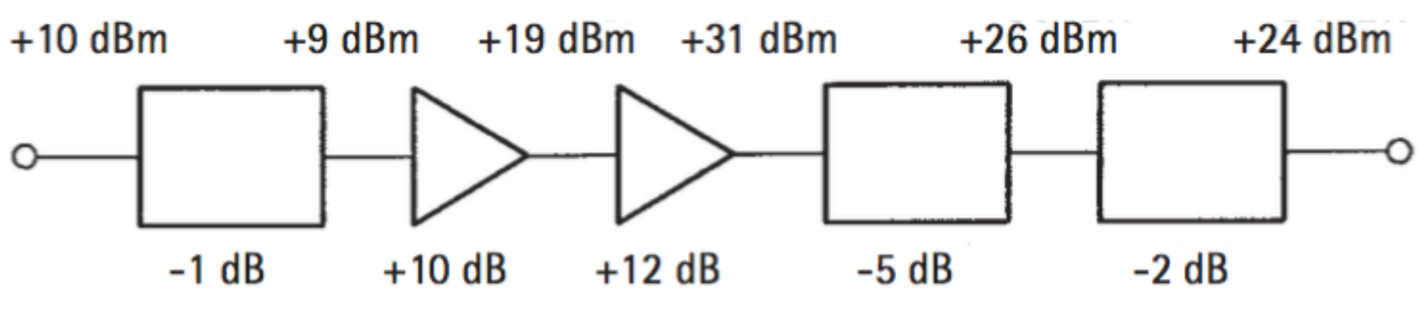
- Sometimes you may also see units such as "dBu" and "dBW".
- dBu = power relative to 1 uW
- dBW = power relative to 1 W

- What is the relationship between dBm and dBu?
- And dBm and dBW?

dBm and dB

- Do not mix up dB and dBm!
- When X dBm power is amplified by Y dB gain, the final power is (X+Y) dBm!

X [dBm] + Y [dB] => X+Y [dBm]



Calculating Power - Ex 2.1

Example 2.1

An amplifier senses a sinusoidal signal and delivers a power of 0 dBm to a load resistance of 50 Ω. Determine the peak-to-peak voltage swing across the load.

Solution:

Since 0 dBm is equivalent to 1 mW, for a sinusoidal having a peak-to-peak amplitude of V_{pp} and hence an rms value of $V_{pp}/(2\sqrt{2})$, we write

$$\frac{V_{pp}^2}{8R_L} = 1\text{ mW}, \qquad (2.7)$$

where $R_L = 50\ \Omega$. Thus,

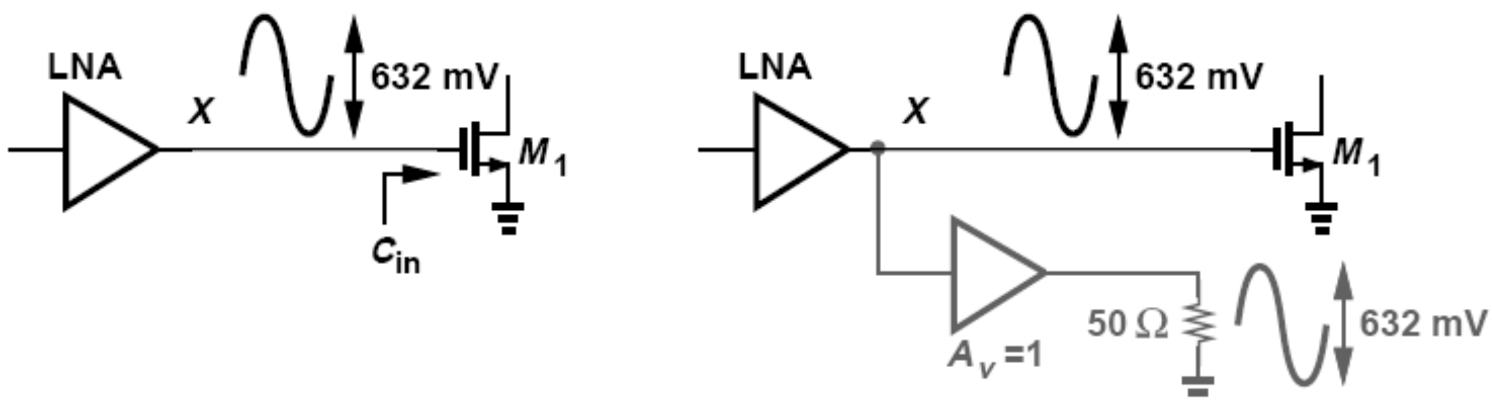
$$V_{pp} = 632\text{ mV}. \qquad (2.8)$$

Calculating Power

- Often power (dBm) is used between parts in a radio system to describe signals propagation.
- But we are not measuring the power in our design calculations.
- We are assuming that the signal is connected to a 50 Ω resistor and we are measuring the power.
- dBm can be used at interfaces that do not necessarily entail power transfer.

What is the output power of this LNA?

- We mentally attach an ideal voltage buffer to node X and drive a 50-Ω load. We then say that the signal at node X has a level of 0 dBm, meaning that if this signal were applied to a 50-Ω load, then it would deliver A mW or B dBm.



Voltage gain, power gain

- If the input and output loads are equal:

- Voltage gain:
- Power gain:

$$
\begin{aligned}
A_V|_{\mathrm{dB}} &= 20\log\frac{V_{out}}{V_{in}} \\
A_P|_{\mathrm{dB}} &= 10\log\frac{P_{out}}{P_{in}}.
\end{aligned}
$$

$$
\begin{aligned}
A_P|_{\mathrm{dB}} &= 10\log\frac{\frac{V_{out}^2}{R_0}}{\frac{V_{in}^2}{R_0}} \\
&= 20\log\frac{V_{out}}{V_{in}} \\
&= A_V|_{\mathrm{dB}},
\end{aligned}
$$

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