EMIMEO : E(rasmus) Mundus on Innovative Microwave Electronics and Optics Master

Foundations of Electromagnetic Wave Propagation – 2nd part

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Chapters:

Chapters:

4. Antennas
    a. Reminder of fundamental concepts
    b. Solutions of Maxwell's equations
    c. The elementary electric dipole
    d. Characteristics of antennas
    e. Wired antennas
    f. Links between antennas
    g. Radar Cross Section
    h. Telecommunications' equations
    i. Antenna arrays
    j. Radiant aperture antennas
    k. Reflector Antennas
    l. Printed antennas
    m. UWB Antennas

Chapters:

0. Microwave domain

1. S-parameters and transmission line
    a. Microwave signals - time and frequency domains
    b. Description of microwave devices by scattering parameters
    c. Exercises on the parameters S
    d. Description of microwave devices by chain matrix

2. Theory of transmission lines

3. Smith Chart and impedance matching
    a. Introduction, uses and principles
    b. Movement along the line
    c. Different methods for impedance matching
    d. Matching by a stub
    e. Matching by double stubs

0. Microwave domain

1. Context of RF and microwave communications

To fill

- **Radio Frequencies** : basis of Wireless communications (unilateral: FM, DVB-T*, GPS, …; bilateral: 2-5G , WIFI, Bluetooth, …)

The near present: **IoT**** (5G, …), **SmartAg** (cashless payment, ticketing, access control, photo activation & social media, Loyalty & gamification, management panel : wearable RFID) and **Smart Cities Applications** (energy, health care, water and waste management)

All this thanks to the use of EM fields and very high frequency signals:

- **EM radiation** family : …………………………………………………………………………………………

Consisting of a **magnetic** and **electric fields** that propagate as a wave

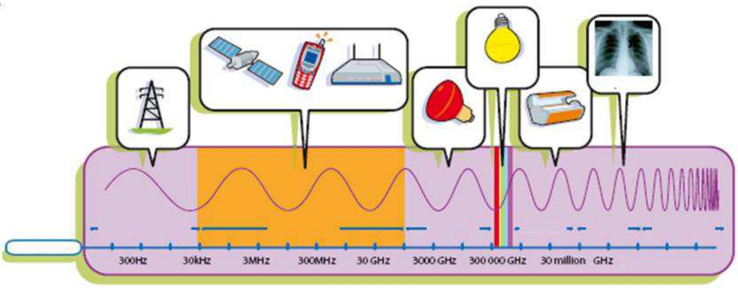
* DVB-T : Digital Video Broadcasting – Terrestrial

** Internet of Things : 30 billion connected objects by 2020, 75 billion by 2025

0. Microwave domain

2. Spectrum of RF and microwave communications

To fill



Definition

Microwaves:

Frequency space between ‘short’ radio waves and infrared in its broadest definition

Centimeter and millimeter wavelengths (100 cm to 1 mm, 300 MHz to 300 GHz) in a more restricted definition

Frequency range from …………… to ……………. in use

What does not change with the frequency level : physics, the law of electromagnetism (Maxwell)

Particularities of microwaves

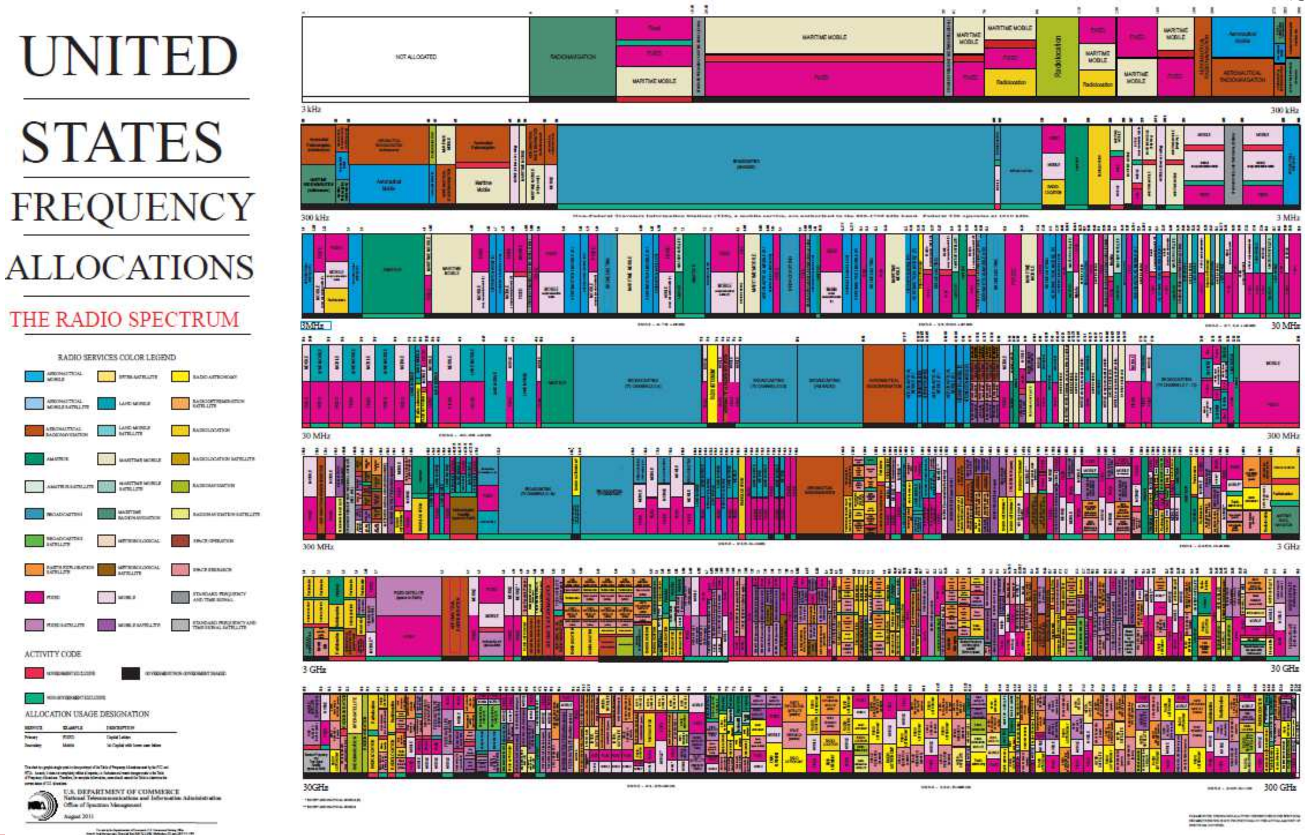
…………………………………………………………………………………………:
a line, depending on its dimensions (especially length) can have an
…………………………………………………………….(specific to microwaves)

Radiation from conductors increases with the frequency: creates coupling, constructive or destructive between components of a circuit

Antennas dimensions related to the wavelength

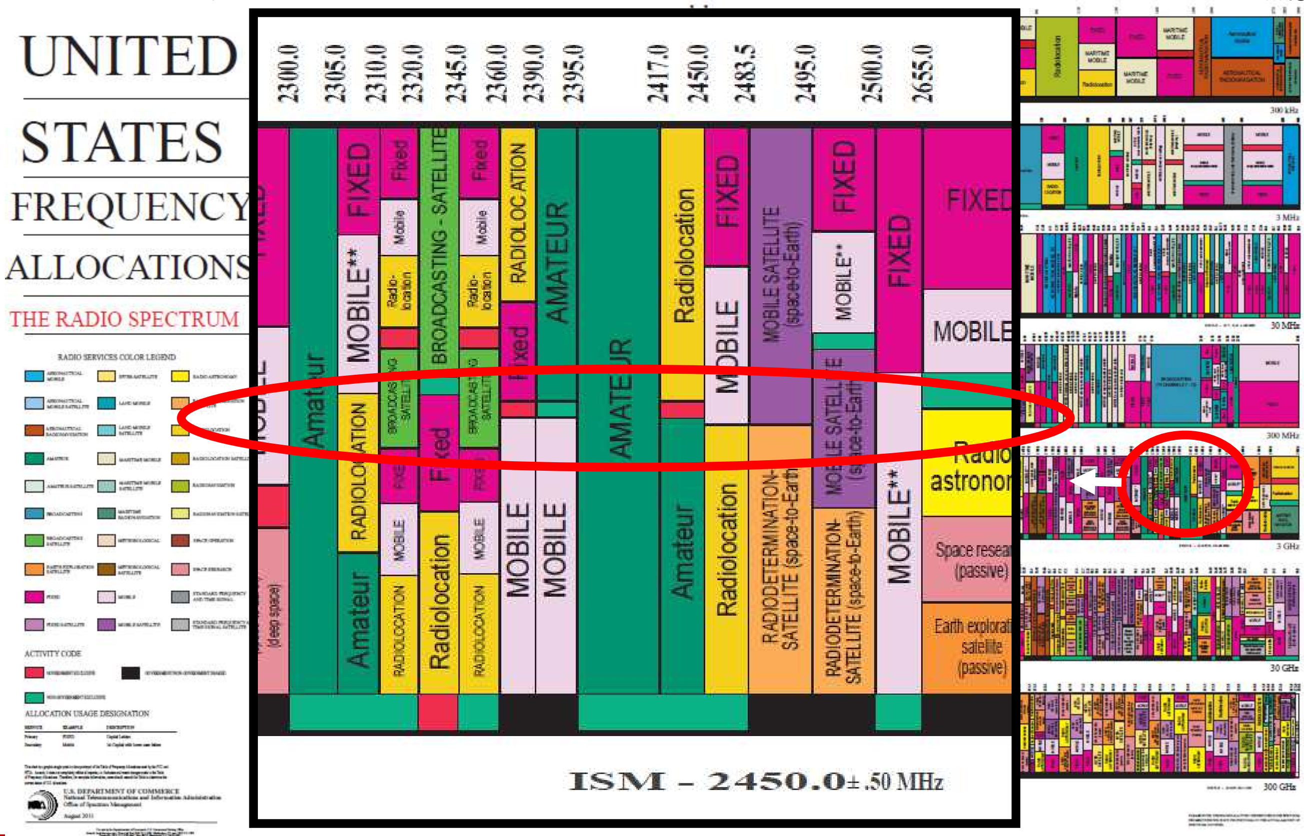
Transistors generate and amplify signals above 150 GHz, the gain decrease with the frequency, the parasitic effects (resistive, capacitive, inductive) increase with the frequency

The signal measurement is delicate and specific to this field



0. Microwave domain

5. Spectrum of RF and microwave communications



0. Microwave domain

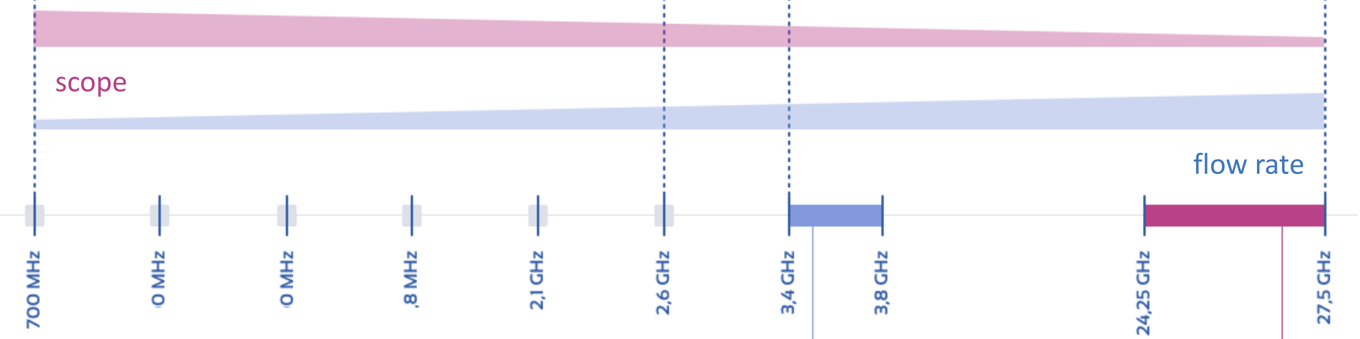
6. example of 5G frequency bands

low bands

already used for current networks (operators are deploying 5G in these bands now)

high bands

new 5G bands, which will address the saturation of currents networks and offer high-speed connections



3.5 GHz band

band "heart" of 5G that offers a good compromise between coverage (scope) and flow rate. In use from 2020

26 GHz band

millimeter band which will be used later (>2023). For targeted uses: major events, industrial uses in specific areas

https://5g.anfr.fr/

0. Microwave domain

7. Some specific tools for microwave communications

Some specific concepts and tools for RF and Microwave communications

Spectrum Analyzers (Signal Analyzers)

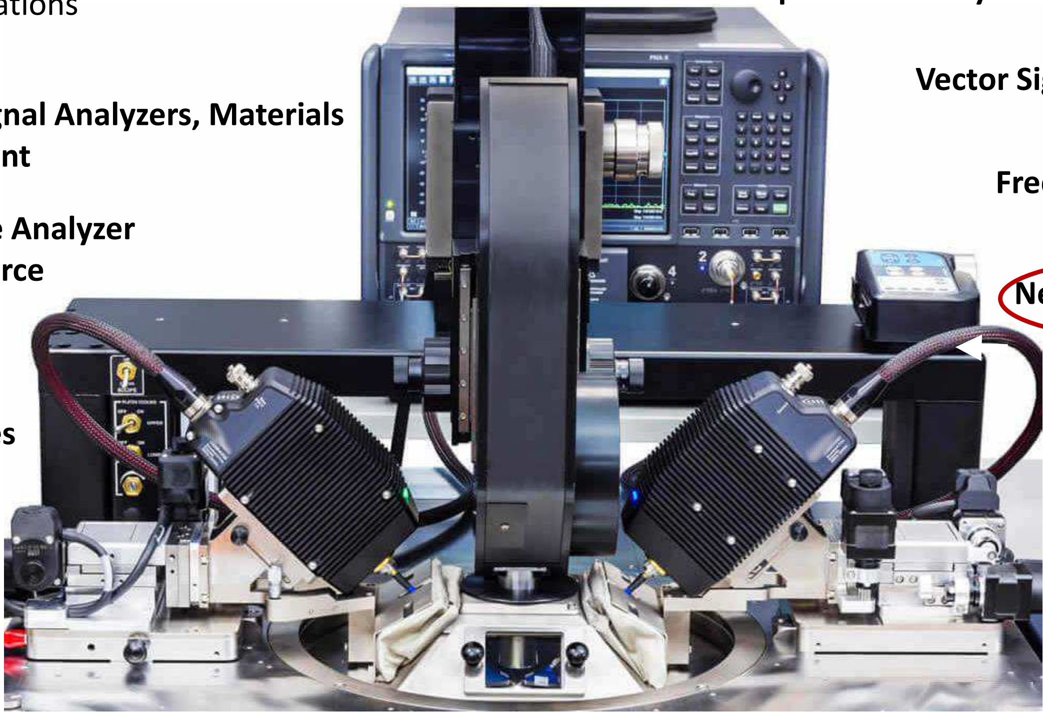
Vector Signal Analyzer

Dynamic Signal Analyzers, Materials Measurement

Frequency Counter

Noise Figure Analyzer & Noise Source

Network Analyzers



Oscilloscopes

Power Meter & Power Sensor

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Characterization of Linear Time Invariant System (LTIS) or Device Under Test (DUT)

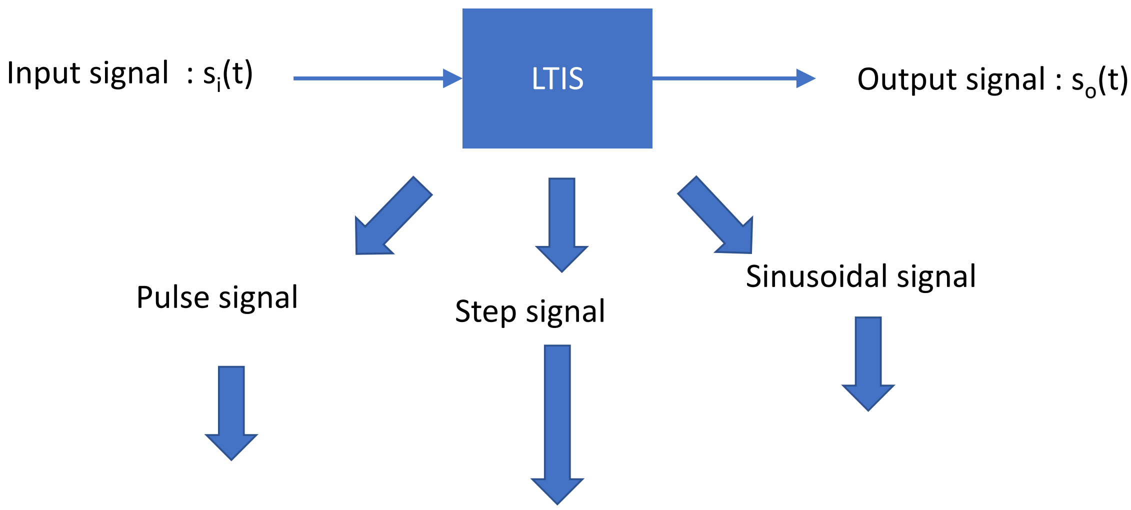
- **Linear** : signal $x_1(t)$ or $x_2(t)$ at the input produce $y_1(t)$ or $y_2(t)$ at the output

then, the signal ………………………………at the input produce …………………….. at the output

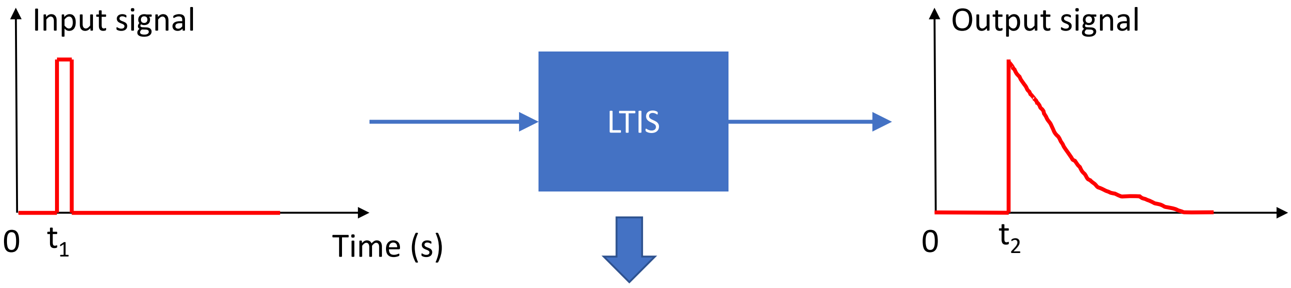
- **Time Invariant** : signal $x_1(t)$ at the input produce $y_1(t)$ at the output

then ………………… at the input produce ……………. at the output

Characterization of Linear Time Invariant System (LTIS) or Device Under Test (DUT)



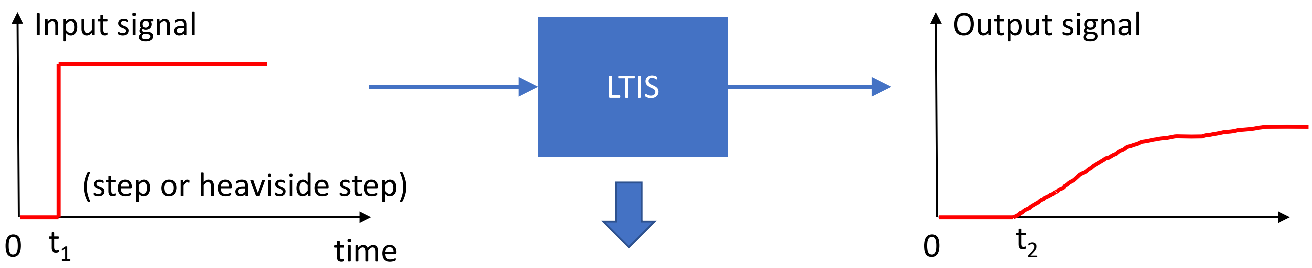
Characterization of Linear Time Invariant System (LTIS)



Impulse response

- ……………………………………………
- ………………………………………………………………………………………………………
- Difficult generation of an ultra-short pulse of high amplitude
- …………………………………………

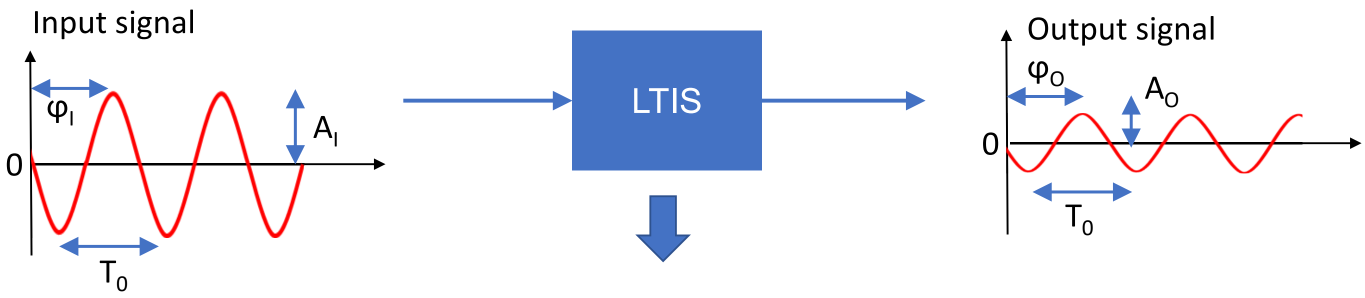
Characterization of Linear Time Invariant System (LTIS)



Step response

- ……………………………………………………………………
- Measurement of LTIS establishment time
- Generation of a Heaviside step with a very short rise time
- ……

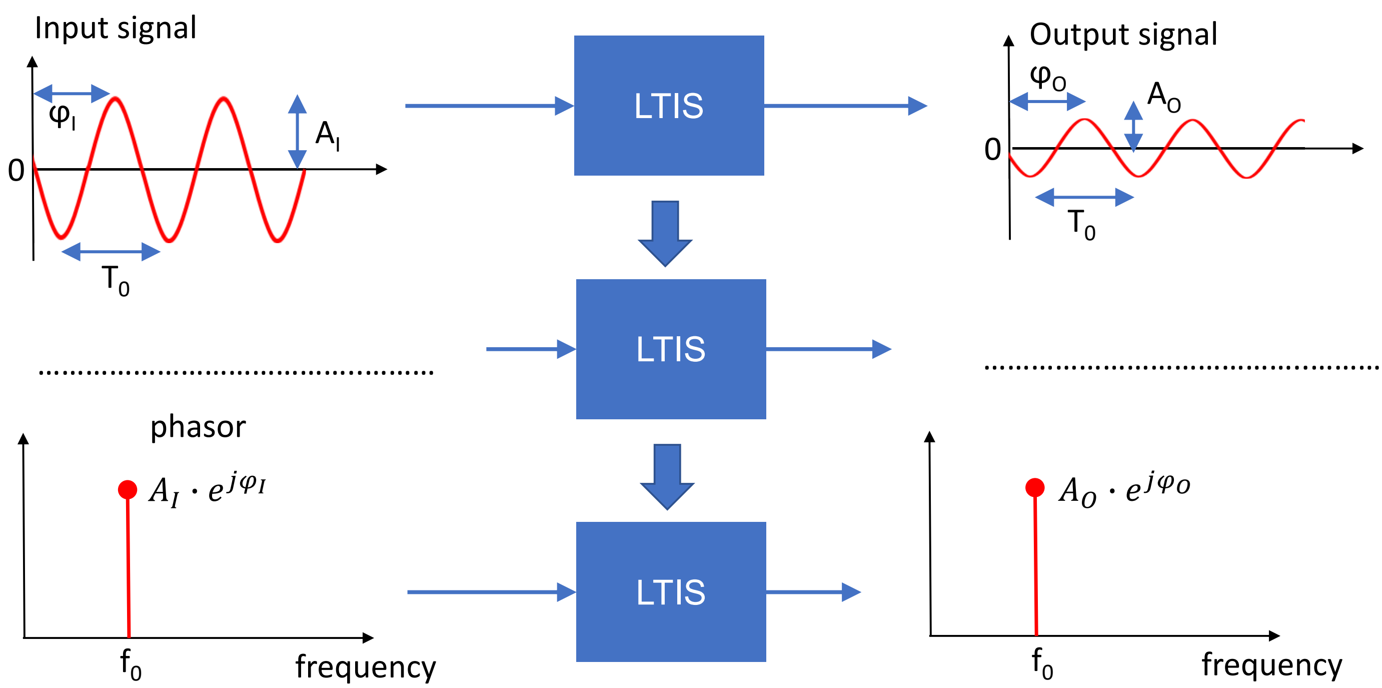
Characterization of Linear Time Invariant System (LTIS)



<u>Harmonic response</u>

- ……………………………………………………………………………
- ……………………………………………………………………………
- Easy generation of a sinusoidal signal LF up to THz
- LTIS → differential equations → no deformation of the sinusoidal shape
- ……………………………………………………………………………

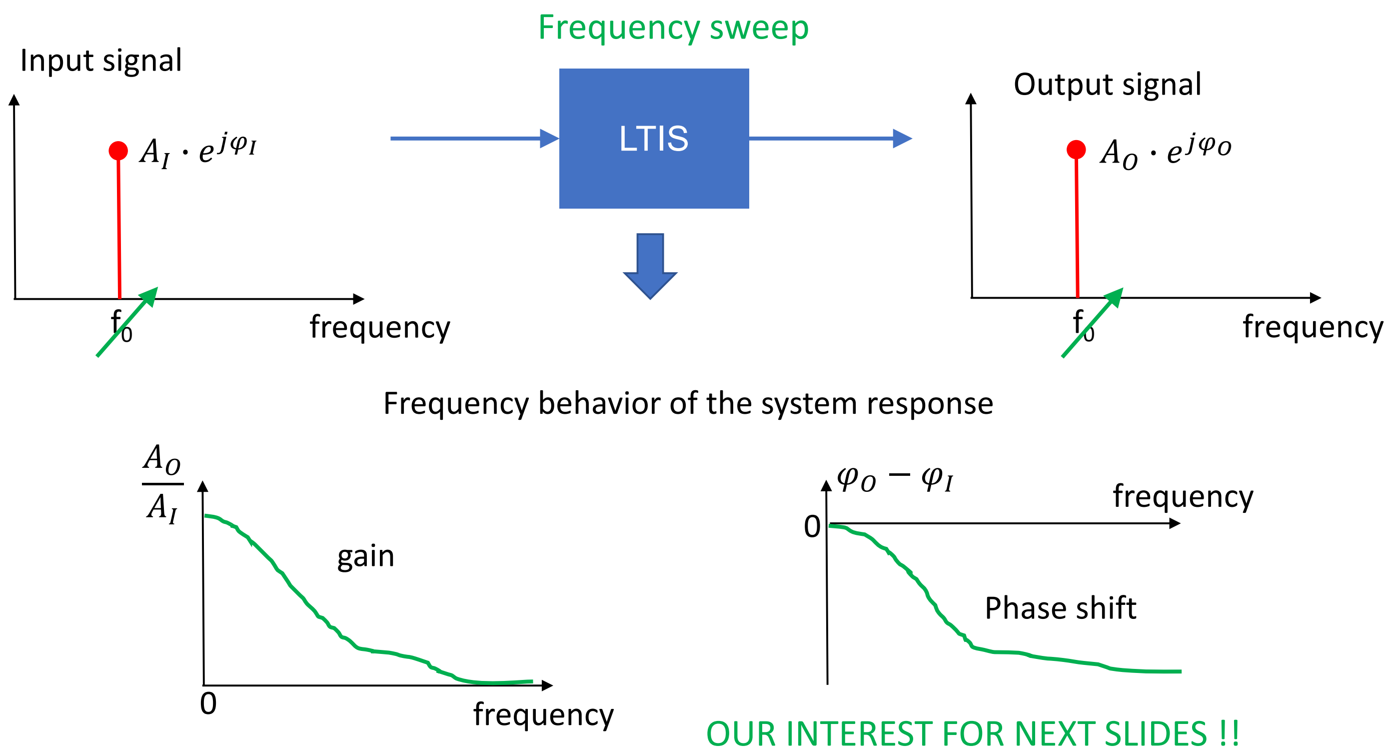
Characterization of Linear Time Invariant System (LTIS)



<u>**Spectrum response**</u>

1. S-parameters and transmission line

7. Microwave signals - time and frequency domains



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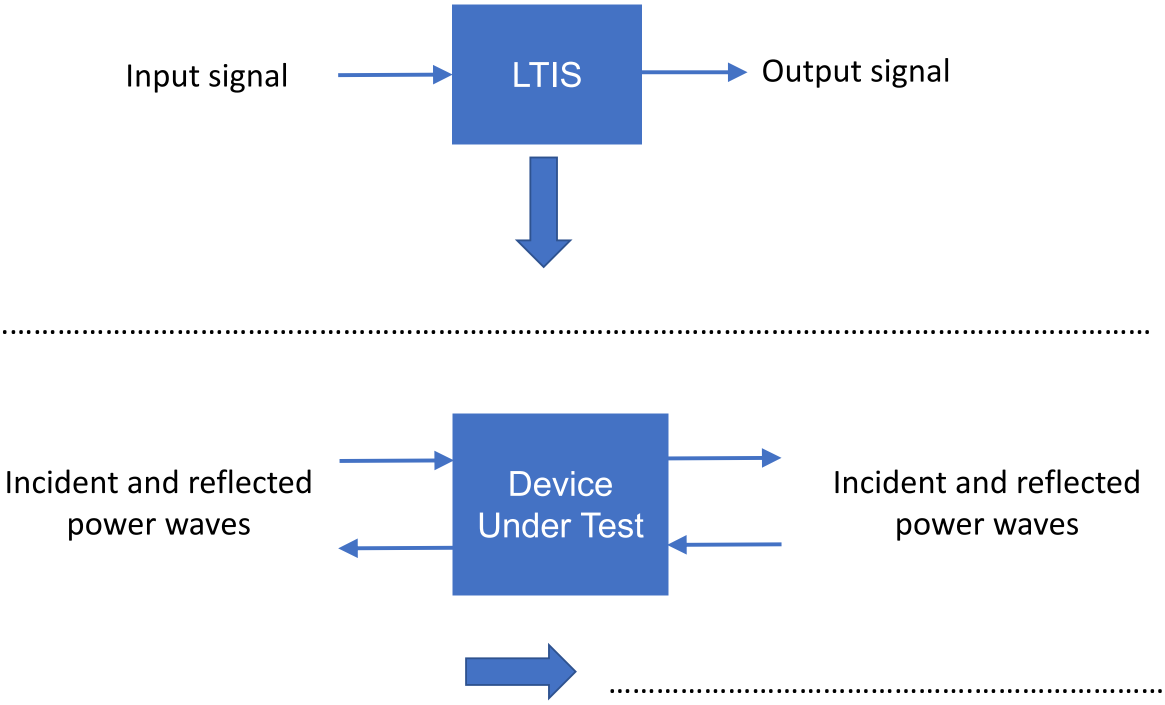
Chapters:

1. S-parameters and transmission line

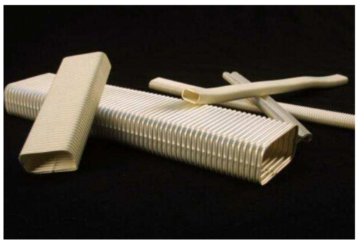
1. Description of microwave devices by scattering parameters



[1] David M. Pozar, Microwave Engineering, Third Edition, John Wiley & Sons Inc.; (ISBN 0-471-17096-8)

1. S-parameters and transmission line

2. Description of microwave devices by scattering parameters



Example : Rectangular waveguides

Only currents on conductor

Microwave signals

Centimetric or millimetric wavelength

....

....

....

....

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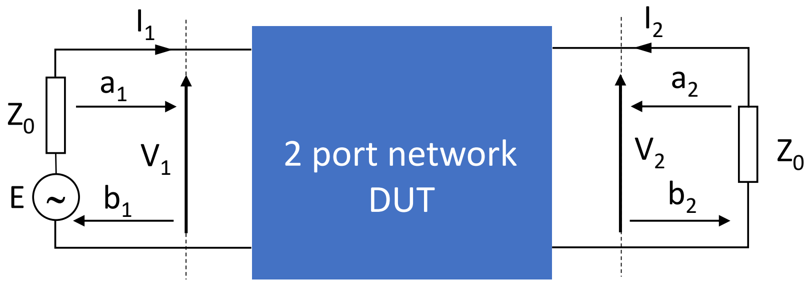
Most RF/microwave components can be represented by a two-port network [2] :
For example, the expression of v_1 is :



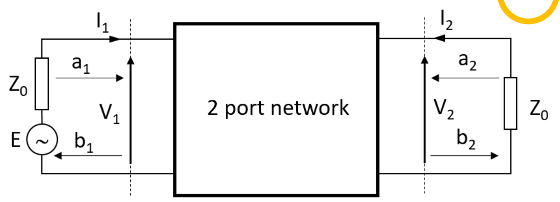
For example, the expression of v_1 is : $v_1(t) = |V_1|\cos(\omega t + \phi) = \mathrm{Re}(|V_1|e^{j(\omega t+\phi)}) = \mathrm{Re}(V_1 e^{j\omega t})$

The wave variables a_1, a_2 (incident waves) and b_1, b_2 (reflected wave) are introduced.

[1] David M. Pozar, Microwave Engineering, Third Edition, John Wiley & Sons Inc.; (ISBN 0-471-17096-8)

1. S-parameters and transmission line

4. Description of microwave devices by scattering parameters



The relationships between the wave variables and the voltage and current variables are defined as :

.... (1)

....

$$a_n = \frac{1}{2}\left(\frac{V_n}{\sqrt{Z_0}} + \sqrt{Z_0} I_n\right)$$

$$b_n = \frac{1}{2}\left(\frac{V_n}{\sqrt{Z_0}} - \sqrt{Z_0} I_n\right)$$

with n = 1 and 2

and Z_0 the reference impedance

with a_n and b_n in ...., so the incident and reflected power can ben expressed at the port n :

Usually, at microwave frequencies, Z_0 = 50 Ω

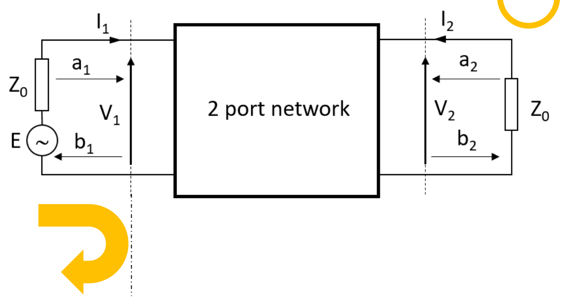
....

[2] Jia-Sheng Hong, M. J. Lancaster, Microstrip Filters for RF/Microwave Applications, John Wiley & Sons Inc.(ISBN: 0-471-38877-7)

1. S-parameters and transmission line

5. Description of microwave devices by scattering parameters

The relationships between the incident and reflected waves and the S parameters are :



....

$$S_{11} = \frac{b_1}{a_1} \; with \; a_2 = 0$$

.... is the ratio between the reflected and the incident wave that is the definition of a ....

This coefficient must be minimize to promote the transmission of the power through the quadripole

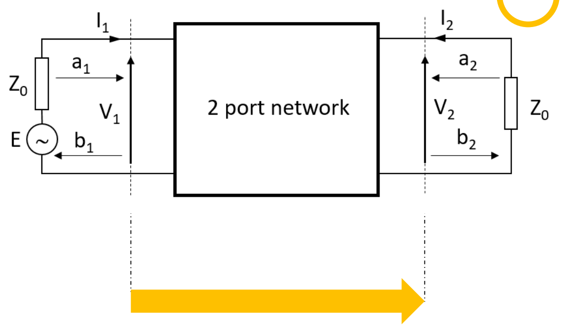
....

The port 2 must be connected to the reference impedance Z_0 for a_2 = 0

1. S-parameters and transmission line

6. Description of microwave devices by scattering parameters

$$b_1 = S_{11}.a_1 + S_{12}.a_2$$
$$b_2 = S_{21}.a_1 + S_{22}.a_2$$



……………………………………

$$S_{21} = \frac{b_2}{a_1} \; with \; a_2 = 0$$

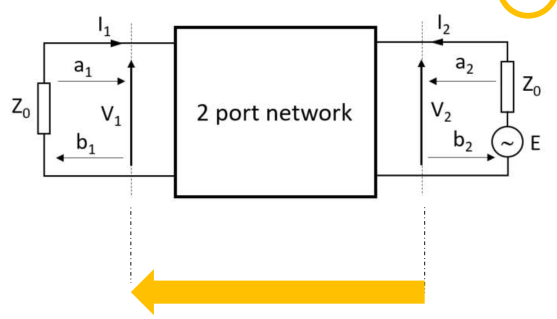
……… is the ratio between the transmitted (port #2) and the incident (port #1) wave that is the definition of a …………………………………… between the port #1 to the port #2. This coefficient must be maximize the power through the quadripole.

The port #2 must be connected to the reference impedance Z_0 for $a_2 = 0$ (no incident wave on the port #2)

1. S-parameters and transmission line

7. Description of microwave devices by scattering parameters

$$b_1 = S_{11}.a_1 + S_{12}.a_2$$
$$b_2 = S_{21}.a_1 + S_{22}.a_2$$



……………………………………

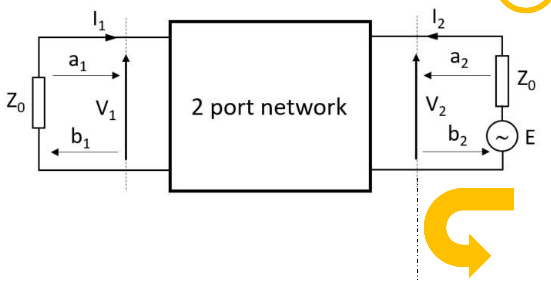
$$S_{12} = \frac{b_1}{a_2} \; with \; a_1 = 0$$

…….. is the ratio between the transmitted (port #1) and the incident (port #2) wave that is the definition of a ……………………………… between the port #2 to the port #1. This coefficient must be maximize the power through the quadripole.

The port #1 must be connected to the reference impedance Z_0 for $a_1 = 0$ (no incident wave on the port #1)

8. Description of microwave devices by scattering parameters

$$b_1 = S_{11}.a_1 + S_{12}.a_2$$
$$b_2 = S_{21}.a_1 + S_{22}.a_2$$

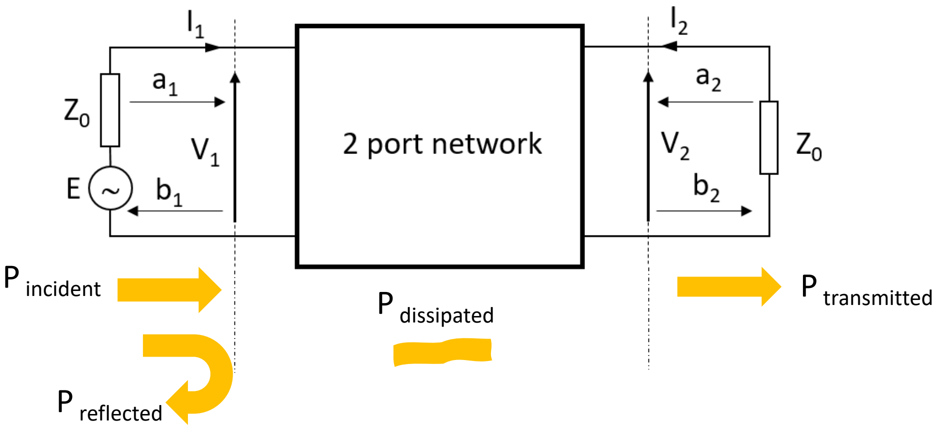


$$S_{22} = \frac{b_2}{a_2}\ with\ a_1 = 0$$

…… is the ratio between the reflected and the incident wave (on port #2) that is the definition of a ……………………………
This coefficient must be minimize the reflected power of the quadripole at port #2.

The port #1 must be connected to the reference impedance Z_0 for $a_1 = 0$
(no incident wave on the port #1)

9. Description of microwave devices by scattering parameters



……………………………………………………………………………………………………

$$\Rightarrow \quad 1 = \frac{P_{reflected}}{P_{incident}} + \frac{P_{dissipated}}{P_{incident}} + \frac{P_{transmitted}}{P_{incident}}$$

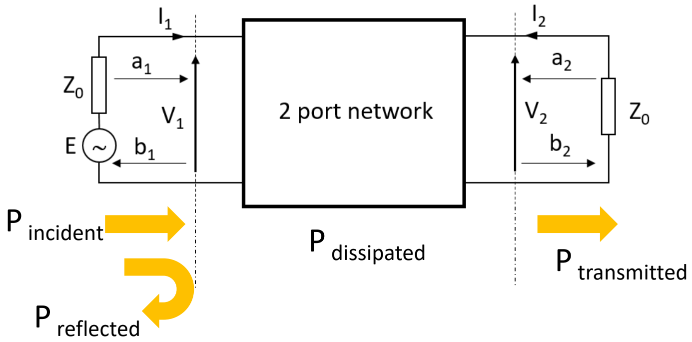
10. Description of microwave devices by scattering parameters

$$1 = \frac{P_{reflected}}{P_{incident}} + \frac{P_{dissipated}}{P_{incident}} + \frac{P_{transmitted}}{P_{incident}}$$

with $P_{incident} = \frac{1}{2}|a_1|^2$

$P_{reflected} = \frac{1}{2}|b_1|^2$

$P_{transmitted} = \frac{1}{2}|b_2|^2$



$$\Rightarrow 1 = \frac{|b_1|^2}{|a_1|^2} + \frac{P_{dissipated}}{P_{incident}} + \frac{|b_2|^2}{|a_1|^2} \quad \Rightarrow \quad \boxed{1 = |S_{11}|^2 + \frac{P_{dissipated}}{P_{incident}} + |S_{21}|^2}$$

For Loss-Less quadripole : $P_{dissipated} = 0$ $\Rightarrow$ $\boxed{1 = |S_{11}|^2 + |S_{21}|^2}$

11. Description of microwave devices by scattering parameters

Each term depends on the frequency:

$$\begin{pmatrix} b_1(f) \\ b_2(f) \end{pmatrix} = \begin{bmatrix} S_{11}(f) & S_{12}(f) \\ S_{21}(f) & S_{22}(f) \end{bmatrix} \begin{pmatrix} a_1(f) \\ a_2(f) \end{pmatrix}$$

$\Rightarrow$ Frequency representation

$\Rightarrow$ Harmonic response with the frequency sweep

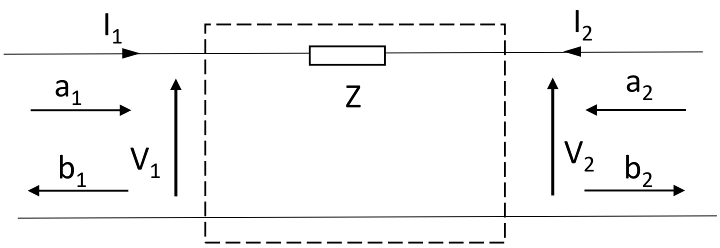
If $S_{21} = S_{12}$ whatever f , then the DUT is reciprocal

If $S_{11} = S_{22}$ $\forall f$, the quadripole is symmetrical

Ideality (lossless) : $[S]^t[S]^* = [1]$ and $S_{11}S_{12}^* + S_{12}S_{22}^* = 0 \Rightarrow \Phi_{12} = \frac{\Phi_{11}+\Phi_{22}}{2} + \frac{\pi}{2}$

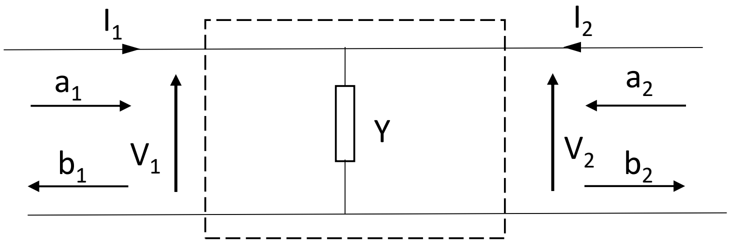
Chapters:

Exercise #1 : S matrix of a serial impedance



From Kirchoff's and Ohm's laws and the expressions (1) of slide 1-4, give the S matrix of the serial impedance Z

Exercise #2 : S matrix of a shunt admittance



as previously, demonstrate that the S matrix for a shunt admittance could be written as:

$$[S] = \begin{bmatrix} -\dfrac{y_n}{y_n+2} & \dfrac{2}{y_n+2} \\ \dfrac{2}{y_n+2} & -\dfrac{y_n}{y_n+2} \end{bmatrix} \quad where \quad y_n = \frac{Y}{Y_0} \; and \; Y_0 = \frac{1}{Z_0}$$

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References:

[1] David M. Pozar, Microwave Engineering, Third Edition, John Wiley & Sons Inc.; (ISBN 0-471-17096-8)
[2] Jia-Sheng Hong, M. J. Lancaster, Microstrip Filters for RF/Microwave Applications, John Wiley & Sons Inc. (ISBN: 0-471-38877-7)
[3] G. Ghione, M. Pirola, Microwave Electronics, Cambridge University Press (ISBN 978-1-107-17027-8)
[4] Richard Collier, Transmission Lines, Cambridge University Press (ISBN 978-1-107-02600-1)
[5] V. Teppati, A. Ferrero, M. Sayed, Modern RF and Microwave Measurement Techniques, Cambridge University Press (ISBN 978-1-107-03641-3)
[6] Y. Kusama and R. Isozaki, ”Compact and Broadband Microstrip Band-Stop Filters with Single Rectangular Stubs”, Applied Sciences, vol. 9, n0 248, 2019,

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