Campi Elettromagnetici

Corso di Laurea in Ingegneria Informatica, Biomedica e delle Telecomunicazioni

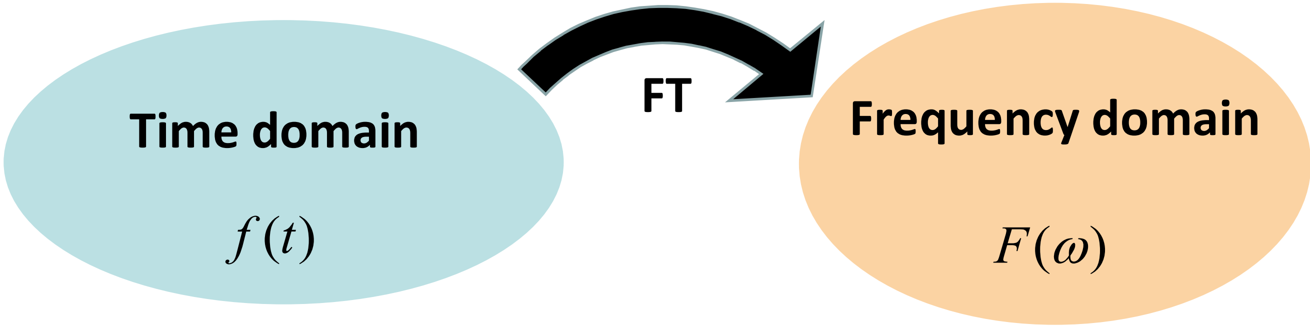
a.a. 2019-2020 – Laurea "Triennale" – Secondo semestre – Secondo anno

Università degli Studi di Napoli "Parthenope"

Stefano Perna

Maxwell equations: Time domain, Frequency domain, Phasors

Frequency domain



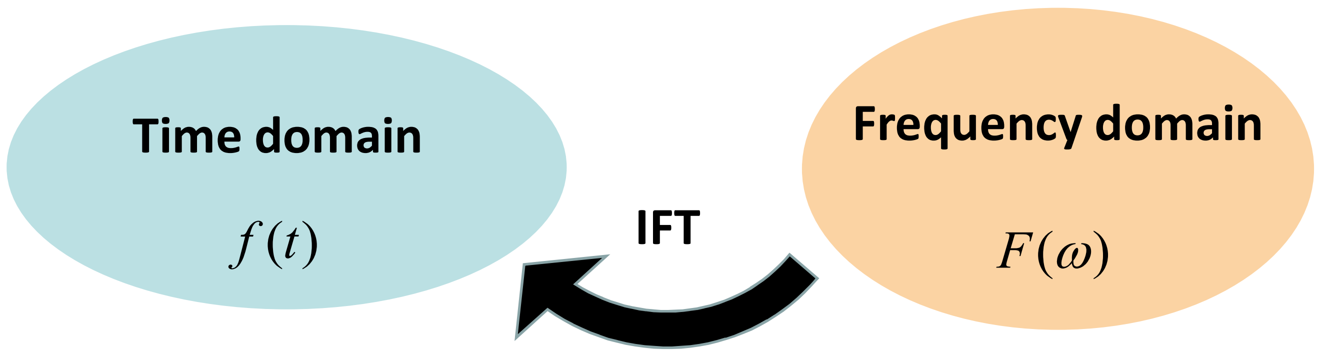
$$F(\omega)=\int_{-\infty}^{+\infty} f(t)e^{-j\omega t}dt$$

Fourier Transform (FT)

1) How to jump back from the Frequency domain to the Time domain

2) Time domain derivative and Fourier Transform

Frequency domain



$$F(\omega)=\int_{-\infty}^{+\infty} f(t)e^{-j\omega t}dt$$

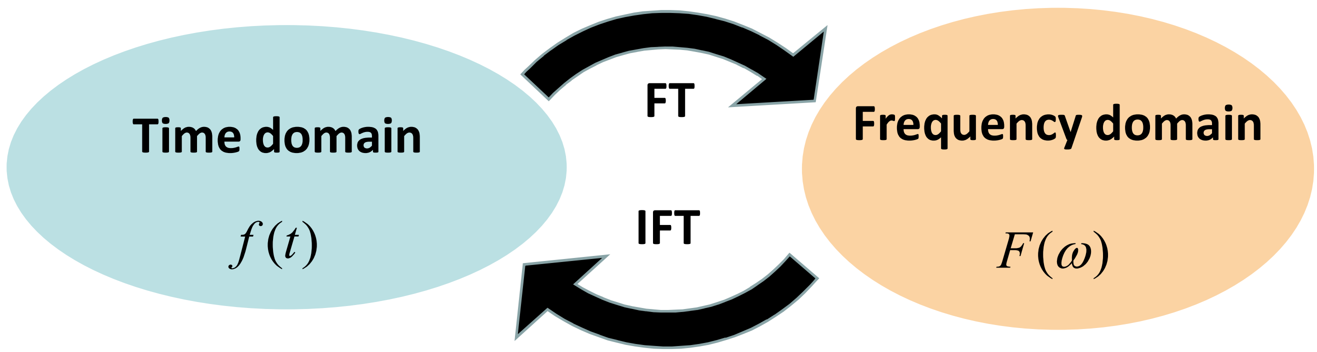
Fourier Transform (FT)

1) How to jump back from the Spectral domain to the Time domain

$$f(t)=\frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega)e^{j\omega t}d\omega$$

Inverse Fourier Transform (IFT)

Frequency domain



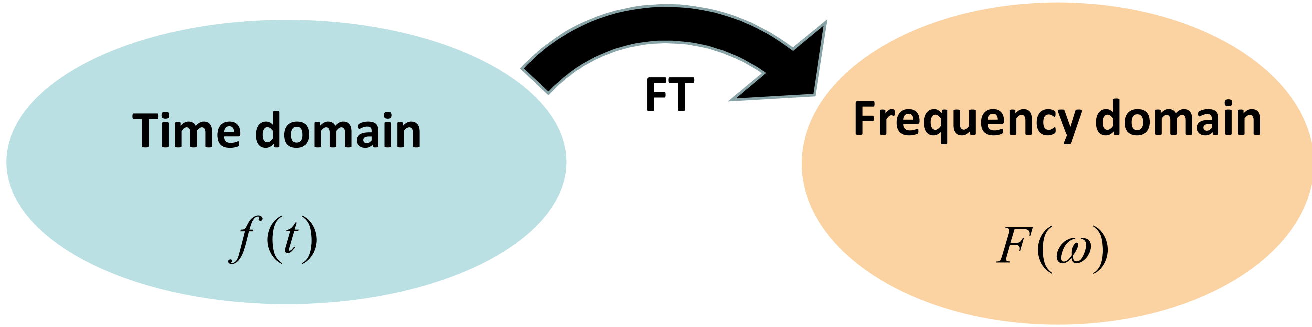
$f(t)$ → **FT** →

$$F(\omega)=\int_{-\infty}^{+\infty} f(t)\,e^{-j\omega t}\,dt$$

$F(\omega)$ → **IFT** →

$$f(t)=\frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega)\,e^{j\omega t}\,d\omega$$

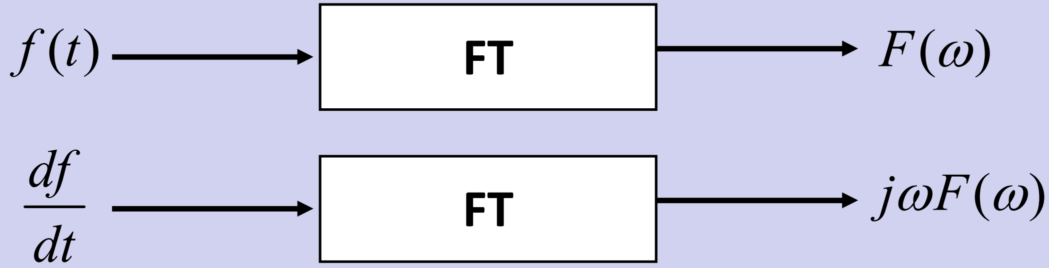
Frequency domain



$$F(\omega)=\int_{-\infty}^{+\infty} f(t)e^{-j\omega t}dt$$

Fourier Transform (FT)

2) Time-domain derivative and Fourier Transform



Frequency domain

- **Fourier Transform and functions of *n* variables**
- **Fourier Transform and vector functions**
- **Fourier Transform and vector functions of *n* variables**

1) How to jump back from the Frequency domain to the Time domain

2) Time domain derivative and Fourier Transform

Fourier Transform and functions of *n* variables

Starting domain

$f(t_1, t_2, t_3, t_4)$

1D-FT

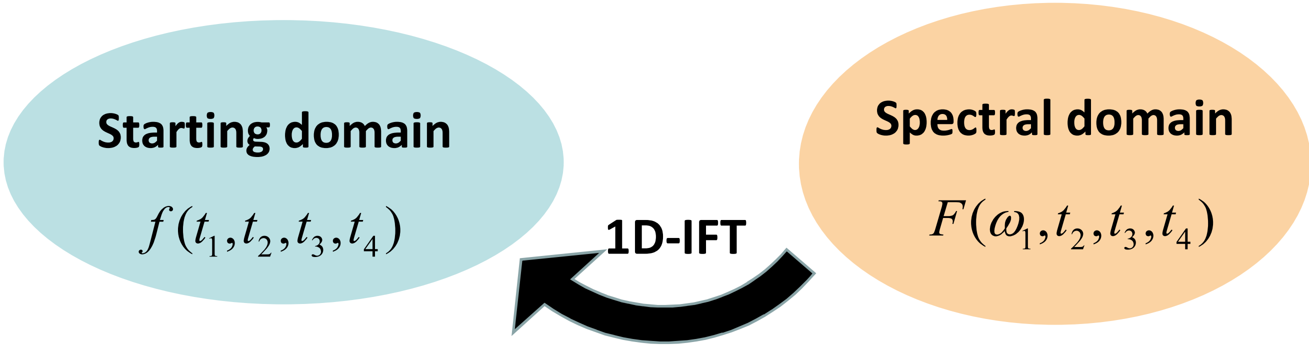
Spectral domain

$F(\omega_1, t_2, t_3, t_4)$

One Dimensional Fourier Transform (1D-FT)

$$F(\omega_1, t_2, t_3, t_4) = \int_{-\infty}^{+\infty} f(t_1, t_2, t_3, t_4)\, e^{-j\omega_1 t_1}\, dt_1$$

Fourier Transform and functions of *n* variables



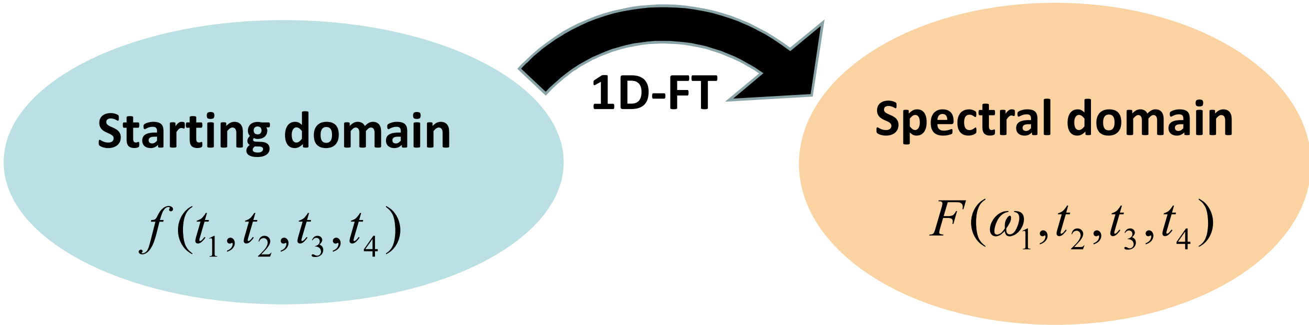
One Dimensional Fourier Transform (1D-FT)

$$F(\omega_1,t_2,t_3,t_4)=\int_{-\infty}^{+\infty} f(t_1,t_2,t_3,t_4)\,e^{-j\omega_1 t_1}\,dt_1$$

1) How to jump back from the Spectral domain to the Time domain

$$f(t_1,t_2,t_3,t_4)=\frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega_1,t_2,t_3,t_4)\,e^{j\omega_1 t_1}\,d\omega_1 \quad \textbf{1D-IFT}$$

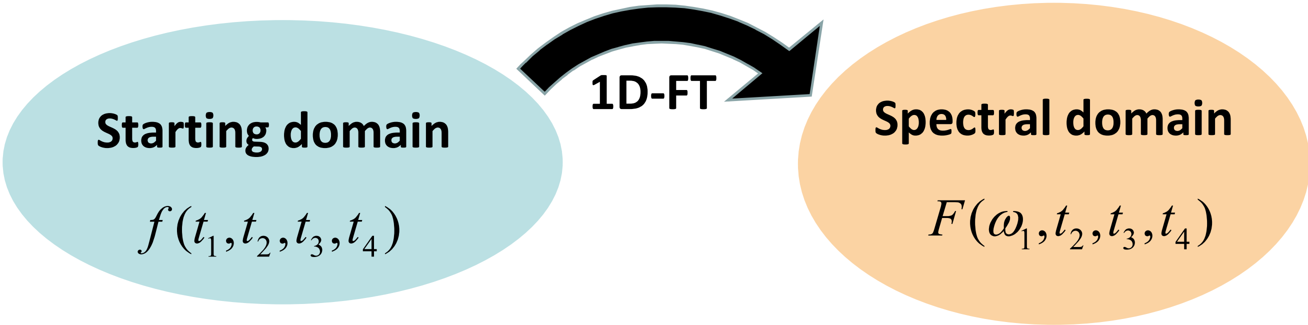
Fourier Transform and functions of *n* variables



$$F(\omega_1,t_2,t_3,t_4)=\int_{-\infty}^{+\infty} f(t_1,t_2,t_3,t_4)\,e^{-j\omega_1 t_1}\,dt_1$$

$$f(t_1,t_2,t_3,t_4)=\frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega_1,t_2,t_3,t_4)\,e^{j\omega_1 t_1}\,d\omega_1$$

Fourier Transform and functions of *n* variables



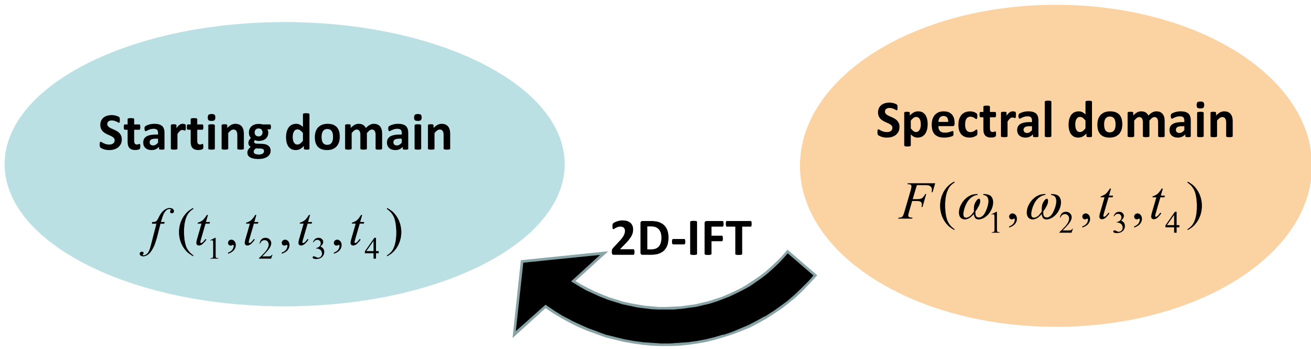
2) Time domain derivative and Fourier Transform

$$f(t_1,t_2,t_3,t_4) \longrightarrow \boxed{\text{1D-FT}} \longrightarrow F(\omega_1,t_2,t_3,t_4)$$

$$\frac{\partial f}{\partial t_1} \longrightarrow \boxed{\text{1D-FT}} \longrightarrow j\omega_1 F(\omega_1,t_2,t_3,t_4)$$

$$\frac{\partial f}{\partial t_2} \longrightarrow \boxed{\text{1D-FT}} \longrightarrow \frac{\partial F(\omega_1,t_2,t_3,t_4)}{\partial t_2}$$

Fourier Transform and functions of *n* variables



Two Dimensional Fourier Transform (2D-FT)

$$F(\omega_1,\omega_2,t_3,t_4)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} dt_1 dt_2 f(t_1,t_2,t_3,t_4)\, e^{-j\omega_1 t_1} e^{-j\omega_2 t_2}$$

1) How to jump back from the Spectral domain to the Time domain

$$f(t_1,t_2,t_3,t_4)=\left(\frac{1}{2\pi}\right)^2 \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} F(\omega_1,\omega_2,t_3,t_4) e^{j\omega_1 t_1} e^{j\omega_2 t_2} d\omega_1 d\omega_2$$ **2D-IFT**

Fourier Transform and functions of *n* variables

Starting domain $f(t_1,t_2,t_3,t_4)$ → **2D-FT** → **Spectral domain** $F(\omega_1,\omega_2,t_3,t_4)$

2) Time domain derivative and Fourier Transform

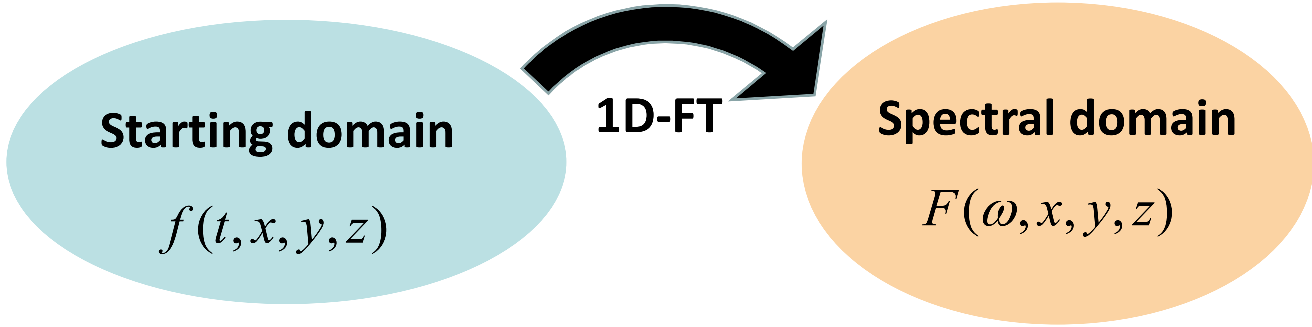
$$f(t_1,t_2,t_3,t_4) \longrightarrow \boxed{\text{2D-FT}} \longrightarrow F(\omega_1,\omega_2,t_3,t_4)$$

$$\frac{\partial f}{\partial t_1} \longrightarrow \boxed{\text{2D-FT}} \longrightarrow j\omega_1 F(\omega_1,\omega_2,t_3,t_4)$$

$$\frac{\partial f}{\partial t_2} \longrightarrow \boxed{\text{2D-FT}} \longrightarrow j\omega_2 F(\omega_1,\omega_2,t_3,t_4)$$

$$\frac{\partial f}{\partial t_3} \longrightarrow \boxed{\text{2D-FT}} \longrightarrow \frac{\partial F(\omega_1,\omega_2,t_3,t_4)}{\partial t_3}$$

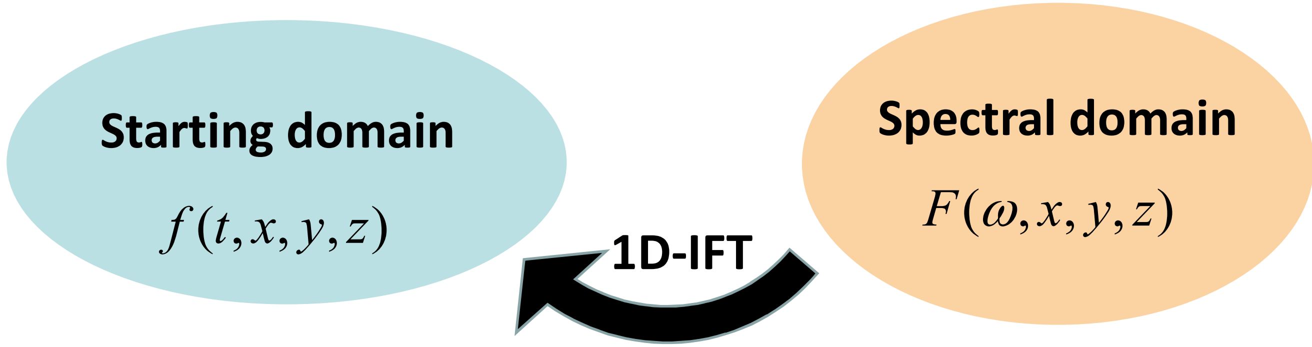
Fourier Transform and functions of *n* variables



One Dimensional Fourier Transform (1D-FT)

$$F(\omega,x,y,z)=\int_{-\infty}^{+\infty} f(t,x,y,z)\,e^{-j\omega t}\,dt$$

Fourier Transform and functions of *n* variables



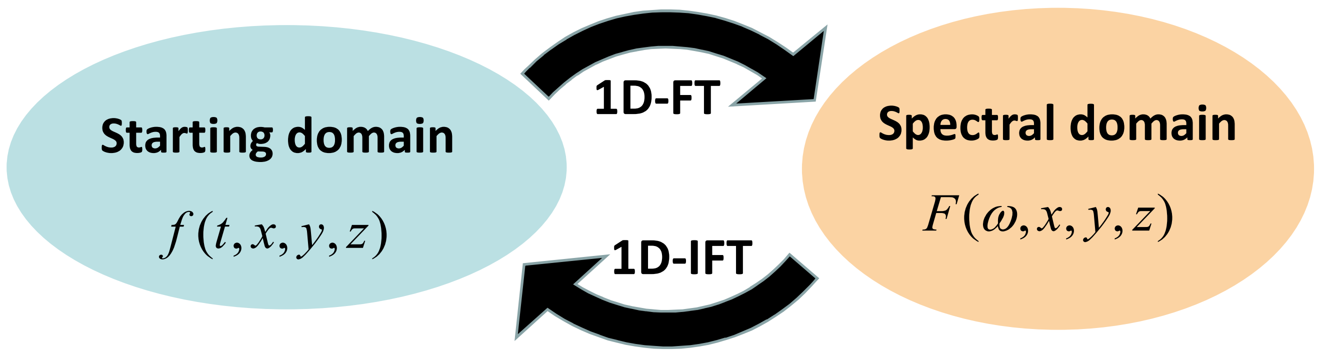
One Dimensional Fourier Transform (1D-FT)

$$F(\omega,x,y,z)=\int_{-\infty}^{+\infty} f(t,x,y,z)\,e^{-j\omega t}\,dt$$

1) How to jump back from the Spectral domain to the Time domain

$$f(t,x,y,z)=\frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega,x,y,z)\,e^{j\omega t}\,d\omega$$ **1D-IFT**

Fourier Transform and functions of *n* variables



$f(t,x,y,z)$ → **1D-FT** →

$$F(\omega,x,y,z) = \int_{-\infty}^{+\infty} f(t,x,y,z)\, e^{-j\omega t}\, dt$$

$F(\omega,x,y,z)$ → **1D-IFT** →

$$f(t,x,y,z) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} F(\omega,x,y,z)\, e^{j\omega t}\, d\omega$$

Fourier Transform and functions of *n* variables

Starting domain $f(t,x,y,z)$ —**1D-FT**→ **Spectral domain** $F(\omega,x,y,z)$

2) Time domain derivative and Fourier Transform

$$f(t,x,y,z) \xrightarrow{\text{1D-FT}} F(\omega,x,y,z)$$

$$\frac{\partial f}{\partial t} \xrightarrow{\text{1D-FT}} j\omega F(\omega,x,y,z)$$

$$\frac{\partial f}{\partial x} \xrightarrow{\text{1D-FT}} \frac{\partial F(\omega,x,y,z)}{\partial x}$$

$$\frac{\partial f}{\partial y} \xrightarrow{\text{1D-FT}} \frac{\partial F(\omega,x,y,z)}{\partial y}$$

Frequency domain

- Fourier Transform and functions of n variables

- Fourier Transform and vector functions

- Fourier Transform and vector functions of n variables

1) How to jump back from the Frequency domain to the Time domain

2) Time domain derivative and Fourier Transform

Fourier Transform and vector functions

Time domain

$$\vec{\mathbf{f}}(t) = f_x(t)\hat{i}_x + f_y(t)\hat{i}_y + f_z(t)\hat{i}_z$$

Frequency domain

$$\vec{\mathbf{F}}(\omega) = F_x(\omega)\hat{i}_x + F_y(\omega)\hat{i}_y + F_z(\omega)\hat{i}_z$$

$f_x(t) \rightarrow$ **1D-FT** $\rightarrow F_x(\omega) = \int_{-\infty}^{+\infty} f_x(t) e^{-j\omega t} dt$

$f_y(t) \rightarrow$ **1D-FT** $\rightarrow F_y(\omega) = \int_{-\infty}^{+\infty} f_y(t) e^{-j\omega t} dt$

$f_z(t) \rightarrow$ **1D-FT** $\rightarrow F_z(\omega) = \int_{-\infty}^{+\infty} f_z(t) e^{-j\omega t} dt$

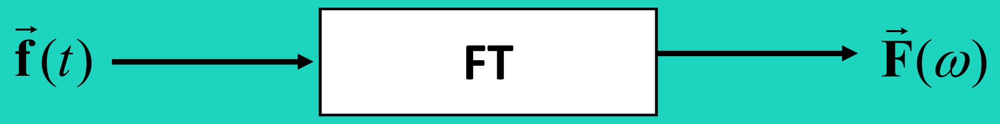
Fourier Transform and vector functions

Time domain

$$\vec{\mathbf{f}}(t) = f_x(t)\hat{i}_x + f_y(t)\hat{i}_y + f_z(t)\hat{i}_z$$

Frequency domain

$$\vec{\mathbf{F}}(\omega) = F_x(\omega)\hat{i}_x + F_y(\omega)\hat{i}_y + F_z(\omega)\hat{i}_z$$



Fourier Transform and vector functions

Time domain

$$\vec{\mathbf{f}}(t) = f_x(t)\hat{i}_x + f_y(t)\hat{i}_y + f_z(t)\hat{i}_z$$

Frequency domain

$$\vec{\mathbf{F}}(\omega) = F_x(\omega)\hat{i}_x + F_y(\omega)\hat{i}_y + F_z(\omega)\hat{i}_z$$

1) How to jump back from the Spectral domain to the Time domain

$F_x(\omega)$ → **1D-IFT** → $f_x(t) = \dfrac{1}{2\pi}\displaystyle\int_{-\infty}^{+\infty} F_x(\omega)e^{j\omega t}d\omega$

$F_y(\omega)$ → **1D-IFT** → $f_y(t) = \dfrac{1}{2\pi}\displaystyle\int_{-\infty}^{+\infty} F_y(\omega)e^{j\omega t}d\omega$

$F_z(\omega)$ → **1D-IFT** → $f_z(t) = \dfrac{1}{2\pi}\displaystyle\int_{-\infty}^{+\infty} F_z(\omega)e^{j\omega t}d\omega$

Fourier Transform and vector functions

Time domain

$$\vec{\mathbf{f}}(t) = f_x(t)\hat{i}_x + f_y(t)\hat{i}_y + f_z(t)\hat{i}_z$$

Frequency domain

$$\vec{\mathbf{F}}(\omega) = F_x(\omega)\hat{i}_x + F_y(\omega)\hat{i}_y + F_z(\omega)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$$\vec{\mathbf{f}}(t) \longrightarrow \boxed{\text{FT}} \longrightarrow \vec{\mathbf{F}}(\omega)$$

$$\frac{d\vec{\mathbf{f}}(t)}{dt} \longrightarrow \boxed{\text{FT}} \longrightarrow j\omega\vec{\mathbf{F}}(\omega) = j\omega F_x(\omega)\hat{i}_x + j\omega F_y(\omega)\hat{i}_y + j\omega F_z(\omega)\hat{i}_z$$

$$\frac{d\vec{\mathbf{f}}(t)}{dt} = \frac{df_x(t)}{dt}\hat{i}_x + \frac{df_y(t)}{dt}\hat{i}_y + \frac{df_z(t)}{dt}\hat{i}_z$$

$$\frac{df_x(t)}{dt} \longrightarrow \boxed{\text{1D-FT}} \longrightarrow j\omega F_x(\omega)$$

$$\frac{df_y(t)}{dt} \longrightarrow \boxed{\text{1D-FT}} \longrightarrow j\omega F_y(\omega)$$

$$\frac{df_z(t)}{dt} \longrightarrow \boxed{\text{1D-FT}} \longrightarrow j\omega F_z(\omega)$$

Fourier Transform and vector functions

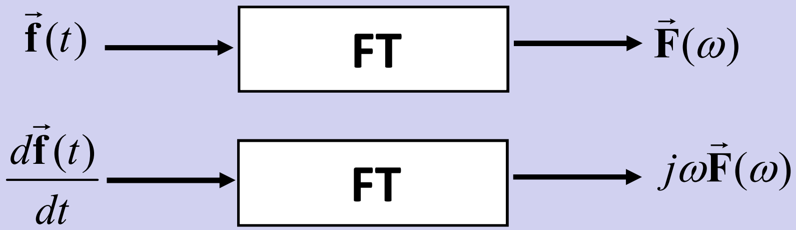
Time domain

$$\vec{\mathbf{f}}(t) = f_x(t)\hat{i}_x + f_y(t)\hat{i}_y + f_z(t)\hat{i}_z$$

Frequency domain

$$\vec{\mathbf{F}}(\omega) = F_x(\omega)\hat{i}_x + F_y(\omega)\hat{i}_y + F_z(\omega)\hat{i}_z$$

2) Time domain derivative and Fourier Transform



Frequency domain

- Fourier Transform and functions of n variables
- Fourier Transform and vector functions
- **Fourier Transform and vector functions of n variables**

1) How to jump back from the Frequency domain to the Time domain

2) Time domain derivative and Fourier Transform

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

Frequency domain

?

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

Frequency domain

?

$f_x(t,x,y,z)$ → **1D-FT** → $F_x(\omega,x,y,z)$

$f_y(t,x,y,z)$ → **1D-FT** → $F_y(\omega,x,y,z)$

$f_z(t,x,y,z)$ → **1D-FT** → $F_z(\omega,x,y,z)$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

Frequency domain

?

$f_x(t,x,y,z)$ → **1D-FT** → $F_x(\omega,x,y,z) = \int_{-\infty}^{+\infty} f_x(t,x,y,z)\,e^{-j\omega t}\,dt$

$f_y(t,x,y,z)$ → **1D-FT** → $F_y(\omega,x,y,z) = \int_{-\infty}^{+\infty} f_y(t,x,y,z)\,e^{-j\omega t}\,dt$

$f_z(t,x,y,z)$ → **1D-FT** → $F_z(\omega,x,y,z) = \int_{-\infty}^{+\infty} f_z(t,x,y,z)\,e^{-j\omega t}\,dt$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

$f_x(t,x,y,z)$ → **1D-FT** → $F_x(\omega,x,y,z) = \int_{-\infty}^{+\infty} f_x(t,x,y,z)\,e^{-j\omega t}\,dt$

$f_y(t,x,y,z)$ → **1D-FT** → $F_y(\omega,x,y,z) = \int_{-\infty}^{+\infty} f_y(t,x,y,z)\,e^{-j\omega t}\,dt$

$f_z(t,x,y,z)$ → **1D-FT** → $F_z(\omega,x,y,z) = \int_{-\infty}^{+\infty} f_z(t,x,y,z)\,e^{-j\omega t}\,dt$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$$t \rightarrow \omega$$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

$$\vec{\mathbf{f}}(t,x,y,z) \longrightarrow \boxed{\text{FT}} \longrightarrow \vec{\mathbf{F}}(\omega,x,y,z)$$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$\omega \to t$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

1) How to jump back from the Spectral domain to the Time domain

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$\omega \rightarrow t$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

1) How to jump back from the Spectral domain to the Time domain

$F_x(\omega,x,y,z)$ → **1D-IFT** →

$F_y(\omega,x,y,z)$ → **1D-IFT** →

$F_z(\omega,x,y,z)$ → **1D-IFT** →

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$\omega \rightarrow t$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

1) How to jump back from the Spectral domain to the Time domain

$F_x(\omega,x,y,z)$ → **1D-IFT** → $$f_x(t,x,y,z) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} F_x(\omega,x,y,z)e^{j\omega t}d\omega$$

$F_y(\omega,x,y,z)$ → **1D-IFT** → $$f_y(t,x,y,z) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} F_y(\omega,x,y,z)e^{j\omega t}d\omega$$

$F_z(\omega,x,y,z)$ → **1D-IFT** → $$f_z(t,x,y,z) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} F_z(\omega,x,y,z)e^{j\omega t}d\omega$$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform $t \rightarrow \omega$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → **FT** → **?**

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{F}}(\omega,x,y,z)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ **FT** $\longrightarrow$ **?**

$$\frac{\partial \vec{\mathbf{f}}(t,\vec{\mathbf{r}})}{\partial t} = \frac{\partial f_x}{\partial t}\hat{i}_x + \frac{\partial f_y}{\partial t}\hat{i}_y + \frac{\partial f_z}{\partial t}\hat{i}_z$$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → **FT** → **?**

$$\frac{\partial \vec{\mathbf{f}}(t,\vec{\mathbf{r}})}{\partial t} = \frac{\partial f_x}{\partial t}\hat{i}_x + \frac{\partial f_y}{\partial t}\hat{i}_y + \frac{\partial f_z}{\partial t}\hat{i}_z$$

$\dfrac{\partial f_x}{\partial t}$ → **1D-FT** → **?**

$\dfrac{\partial f_y}{\partial t}$ → **1D-FT** → **?**

$\dfrac{\partial f_z}{\partial t}$ → **1D-FT** → **?**

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \to \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \to \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → **FT** → **?**

$$\frac{\partial \vec{\mathbf{f}}(t,\vec{\mathbf{r}})}{\partial t} = \frac{\partial f_x}{\partial t}\hat{i}_x + \frac{\partial f_y}{\partial t}\hat{i}_y + \frac{\partial f_z}{\partial t}\hat{i}_z$$

$\dfrac{\partial f_x}{\partial t}$ → **1D-FT** → $j\omega F_x(\omega,x,y,z)$

$\dfrac{\partial f_y}{\partial t}$ → **1D-FT** → $j\omega F_y(\omega,x,y,z)$

$\dfrac{\partial f_z}{\partial t}$ → **1D-FT** → $j\omega F_z(\omega,x,y,z)$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform $t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → **FT** → $j\omega F_x(\omega,x,y,z)\hat{i}_x + j\omega F_y(\omega,x,y,z)\hat{i}_y + j\omega F_z(\omega,x,y,z)\hat{i}_z$

$$\frac{\partial \vec{\mathbf{f}}(t,\vec{\mathbf{r}})}{\partial t} = \frac{\partial f_x}{\partial t}\hat{i}_x + \frac{\partial f_y}{\partial t}\hat{i}_y + \frac{\partial f_z}{\partial t}\hat{i}_z$$

$\dfrac{\partial f_x}{\partial t}$ → **1D-FT** → $j\omega F_x(\omega,x,y,z)$

$\dfrac{\partial f_y}{\partial t}$ → **1D-FT** → $j\omega F_y(\omega,x,y,z)$

$\dfrac{\partial f_z}{\partial t}$ → **1D-FT** → $j\omega F_z(\omega,x,y,z)$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → **FT** → $j\omega\vec{\mathbf{F}}(\omega,x,y,z) = j\omega F_x(\omega,x,y,z)\hat{i}_x + j\omega F_y(\omega,x,y,z)\hat{i}_y + j\omega F_z(\omega,x,y,z)\hat{i}_z$

$$\frac{\partial \vec{\mathbf{f}}(t,\vec{\mathbf{r}})}{\partial t} = \frac{\partial f_x}{\partial t}\hat{i}_x + \frac{\partial f_y}{\partial t}\hat{i}_y + \frac{\partial f_z}{\partial t}\hat{i}_z$$

$\dfrac{\partial f_x}{\partial t}$ → **1D-FT** → $j\omega F_x(\omega,x,y,z)$

$\dfrac{\partial f_y}{\partial t}$ → **1D-FT** → $j\omega F_y(\omega,x,y,z)$

$\dfrac{\partial f_z}{\partial t}$ → **1D-FT** → $j\omega F_z(\omega,x,y,z)$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

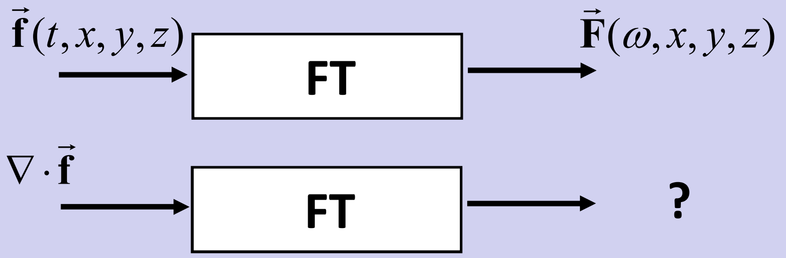
$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$



Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\nabla \cdot \vec{\mathbf{f}}$ → **FT** → **?**

$$\nabla \cdot \vec{\mathbf{f}}\left(t,\vec{\mathbf{r}}\right) = \frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y} + \frac{\partial f_z}{\partial z}$$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \to \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \to \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\nabla \cdot \vec{\mathbf{f}}$ → **FT** → **?**

$$\nabla \cdot \vec{\mathbf{f}}\left(t,\vec{\mathbf{r}}\right) = \frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y} + \frac{\partial f_z}{\partial z}$$

$\frac{\partial f_x}{\partial x}$ → **1D-FT** → **?**

$\frac{\partial f_y}{\partial y}$ → **1D-FT** → **?**

$\frac{\partial f_z}{\partial z}$ → **1D-FT** → **?**

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\nabla \cdot \vec{\mathbf{f}}$ → **FT** → **?**

$$\nabla \cdot \vec{\mathbf{f}}\left(t,\vec{\mathbf{r}}\right) = \frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y} + \frac{\partial f_z}{\partial z}$$

$\dfrac{\partial f_x}{\partial x}$ → **1D-FT** → $\dfrac{\partial F_x(\omega,x,y,z)}{\partial x}$

$\dfrac{\partial f_y}{\partial y}$ → **1D-FT** → $\dfrac{\partial F_y(\omega,x,y,z)}{\partial y}$

$\dfrac{\partial f_z}{\partial z}$ → **1D-FT** → $\dfrac{\partial F_z(\omega,x,y,z)}{\partial z}$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\nabla \cdot \vec{\mathbf{f}}$ → **FT** → $\nabla \cdot \vec{\mathbf{F}}(\omega,x,y,z)$

$$\nabla \cdot \vec{\mathbf{f}}\,(t,\vec{\mathbf{r}}) = \frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y} + \frac{\partial f_z}{\partial z}$$

$\frac{\partial f_x}{\partial x}$ → **1D-FT** → $\frac{\partial F_x(\omega,x,y,z)}{\partial x}$

$\frac{\partial f_y}{\partial y}$ → **1D-FT** → $\frac{\partial F_y(\omega,x,y,z)}{\partial y}$

$\frac{\partial f_z}{\partial z}$ → **1D-FT** → $\frac{\partial F_z(\omega,x,y,z)}{\partial z}$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \to \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \to \omega$

$\vec{\mathbf{f}}(t,x,y,z)$ → **FT** → $\vec{\mathbf{F}}(\omega,x,y,z)$

$\nabla \times \vec{\mathbf{f}}$ → **FT** → $\nabla \times \vec{\mathbf{F}}(\omega,x,y,z)$

$$\nabla \times \vec{\mathbf{f}}(t,\vec{\mathbf{r}}) = \left(\frac{\partial f_z}{\partial y} - \frac{\partial f_y}{\partial z}\right)\hat{i}_x + \left(\frac{\partial f_x}{\partial z} - \frac{\partial f_z}{\partial x}\right)\hat{i}_y + \left(\frac{\partial f_y}{\partial x} - \frac{\partial f_x}{\partial y}\right)\hat{i}_z$$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(t,x,y,z) = f_x(t,x,y,z)\hat{i}_x + f_y(t,x,y,z)\hat{i}_y + f_z(t,x,y,z)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(\omega,x,y,z) = F_x(\omega,x,y,z)\hat{i}_x + F_y(\omega,x,y,z)\hat{i}_y + F_z(\omega,x,y,z)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$$\vec{\mathbf{f}}(t,x,y,z) \longrightarrow \boxed{\text{FT}} \longrightarrow \vec{\mathbf{F}}(\omega,x,y,z)$$

$$\frac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow \boxed{\text{FT}} \longrightarrow j\omega\vec{\mathbf{F}}(\omega,x,y,z)$$

$$\nabla \cdot \vec{\mathbf{f}} \longrightarrow \boxed{\text{FT}} \longrightarrow \nabla \cdot \vec{\mathbf{F}}(\omega,x,y,z)$$

$$\nabla \times \vec{\mathbf{f}} \longrightarrow \boxed{\text{FT}} \longrightarrow \nabla \times \vec{\mathbf{F}}(\omega,x,y,z)$$

Fourier Transform and vector functions of *n* variables

Time domain

$$\vec{\mathbf{f}}(x,y,z,t) = f_x(x,y,z,t)\hat{i}_x + f_y(x,y,z,t)\hat{i}_y + f_z(x,y,z,t)\,\hat{i}_z$$

$t \rightarrow \omega$

Frequency domain

$$\vec{\mathbf{F}}(x,y,z,\omega) = F_x(x,y,z,\omega)\hat{i}_x + F_y(x,y,z,\omega)\hat{i}_y + F_z(x,y,z,\omega)\hat{i}_z$$

2) Time domain derivative and Fourier Transform

$t \rightarrow \omega$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ **FT** $\longrightarrow j\omega\vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

Maxwell equations
Time domain & Frequency domain

Time domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \rightarrow \omega$

Frequency domain

$t \rightarrow \omega$

$\vec{\mathbf{f}}(x,y,z,t)$ →	FT	→ $\vec{\mathbf{F}}(x,y,z,\omega)$
$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ →	FT	→ $j\omega\vec{\mathbf{F}}(x,y,z,\omega)$
$\nabla \cdot \vec{\mathbf{f}}$ →	FT	→ $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$
$\nabla \times \vec{\mathbf{f}}$ →	FT	→ $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \\ \end{cases}$$

$t \rightarrow \omega$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \rightarrow \omega$

Frequency domain

$$\{$$

$t \rightarrow \omega$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ **FT** $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$

$\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) \longrightarrow$ **FT** $\longrightarrow \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$ $\quad t \rightarrow \omega$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ **FT** $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$

$\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) \longrightarrow$ **FT** $\longrightarrow \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$t \rightarrow \omega$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega\vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{b}}(\vec{\mathbf{r}},t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$t \rightarrow \omega$

$$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow \boxed{\text{FT}} \longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$$

$$\frac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow \boxed{\text{FT}} \longrightarrow j\omega\vec{\mathbf{F}}(x,y,z,\omega)$$

$$\nabla \cdot \vec{\mathbf{f}} \longrightarrow \boxed{\text{FT}} \longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$$

$$\nabla \times \vec{\mathbf{f}} \longrightarrow \boxed{\text{FT}} \longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$$

$$\vec{\mathbf{b}}(\vec{\mathbf{r}},t) \longrightarrow \boxed{\text{FT}} \longrightarrow \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$$

$$\frac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \longrightarrow \boxed{\text{FT}} \longrightarrow j\omega\vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$$

Maxwell equations
Time domain & Frequency domain

Time domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \rightarrow \omega$

Frequency domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)
\end{cases}
$$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$ $\quad t \rightarrow \omega$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{b}}(\vec{\mathbf{r}},t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$

$\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$\vec{\mathbf{f}}(x,y,z,t)$ → FT → $\vec{\mathbf{F}}(x,y,z,\omega)$ ($t \rightarrow \omega$)

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → FT → $j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}}$ → FT → $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}}$ → FT → $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{h}}(\vec{\mathbf{r}},t)$ → FT → $\vec{\mathbf{H}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

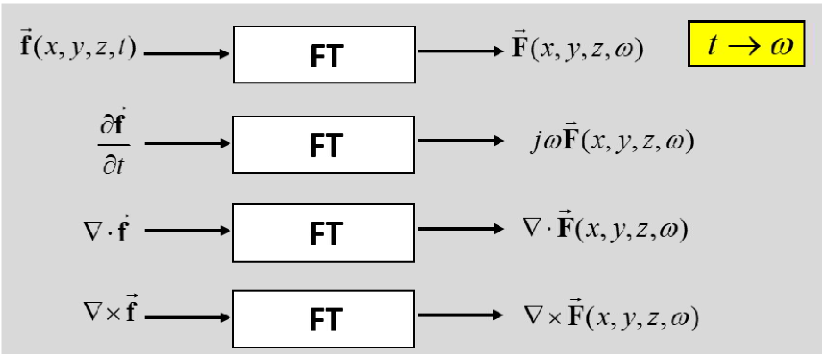
Time domain

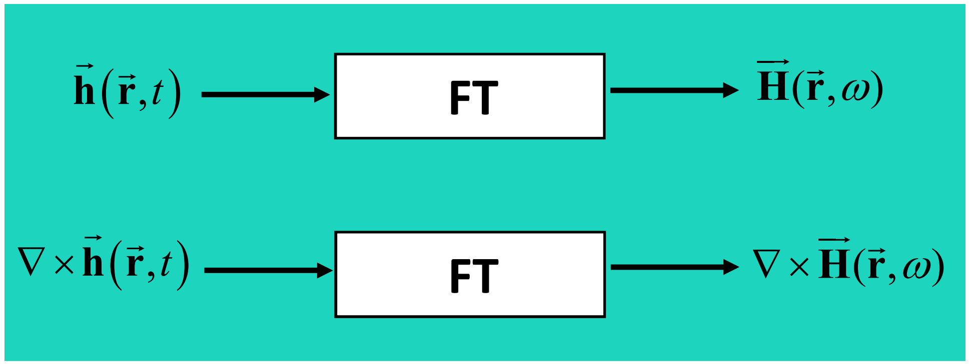
$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \rightarrow \omega$

Frequency domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)
\end{cases}
$$





Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$\vec{\mathbf{f}}(x,y,z,t)$ → **FT** → $\vec{\mathbf{F}}(x,y,z,\omega)$ $t \rightarrow \omega$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → **FT** → $j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}}$ → **FT** → $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}}$ → **FT** → $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{h}}(\vec{\mathbf{r}},t)$ → **FT** → $\vec{\mathbf{H}}(\vec{\mathbf{r}},\omega)$

$\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t)$ → **FT** → $\nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$\vec{\mathbf{f}}(x,y,z,t)$ → **FT** → $\vec{\mathbf{F}}(x,y,z,\omega)$ ($t \rightarrow \omega$)

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → **FT** → $j\omega\vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}}$ → **FT** → $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}}$ → **FT** → $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$ → **FT** → $\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$ $\quad t \rightarrow \omega$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{d}}(\vec{\mathbf{r}},t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

$\dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$t \rightarrow \omega$

$\vec{\mathbf{f}}(x,y,z,t)$ → FT → $\vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → FT → $j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}}$ → FT → $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}}$ → FT → $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$ → FT → $\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

$\dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t}$ → FT → $j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$t \rightarrow \omega$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{j}}(\vec{\mathbf{r}},t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \to \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \end{cases}$$

$\vec{\mathbf{f}}(x,y,z,t)$ → FT → $\vec{\mathbf{F}}(x,y,z,\omega)$ $\quad t \to \omega$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → FT → $j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}}$ → FT → $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}}$ → FT → $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{j}}(\vec{\mathbf{r}},t)$ → FT → $\vec{\mathbf{J}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

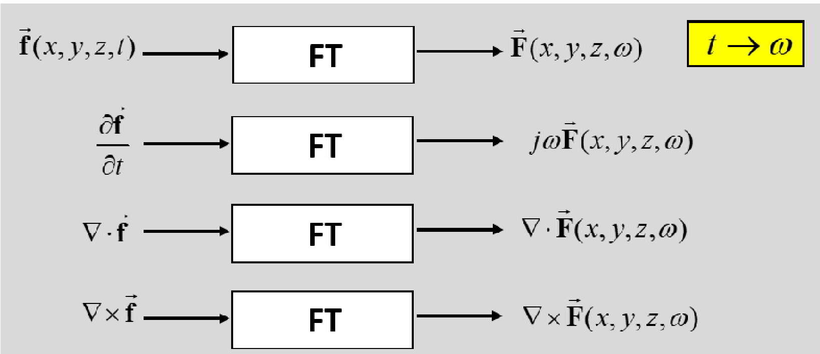
Time domain

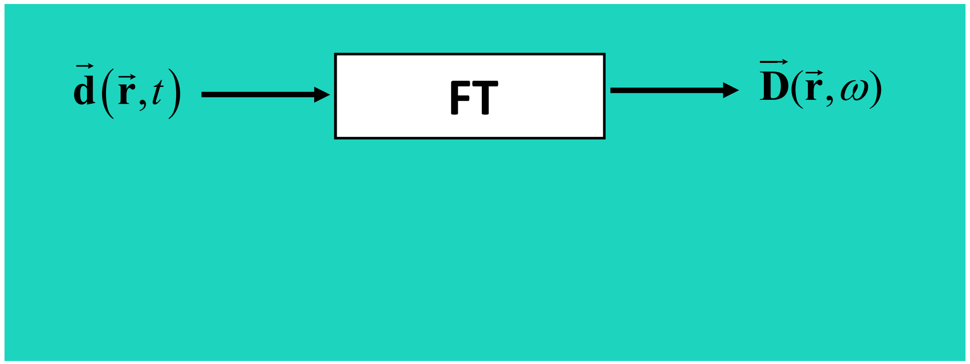
$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \rightarrow \omega$

Frequency domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\
\nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega)
\end{cases}
$$





Maxwell equations
Time domain & Frequency domain

Time domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \to \omega$

Frequency domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\
\nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega)
\end{cases}
$$

$t \to \omega$

$\vec{\mathbf{f}}(x,y,z,t)$ → FT → $\vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → FT → $j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}}$ → FT → $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}}$ → FT → $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$ → FT → $\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

$\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t)$ → FT → $\nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases}\nabla\times\vec{\mathbf{e}}(\vec{\mathbf{r}},t)=-\dfrac{\partial\vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t}\\ \nabla\times\vec{\mathbf{h}}(\vec{\mathbf{r}},t)=\dfrac{\partial\vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t}+\vec{\mathbf{j}}(\vec{\mathbf{r}},t)\\ \nabla\cdot\vec{\mathbf{d}}(\vec{\mathbf{r}},t)=\rho(\vec{\mathbf{r}},t)\\ \nabla\cdot\vec{\mathbf{b}}(\vec{\mathbf{r}},t)=0\end{cases}$$

$t\rightarrow\omega$

Frequency domain

$$\begin{cases}\nabla\times\vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)=-j\omega\vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)\\ \nabla\times\vec{\mathbf{H}}(\vec{\mathbf{r}},\omega)=j\omega\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)+\vec{\mathbf{J}}(\vec{\mathbf{r}},\omega)\\ \nabla\cdot\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)\end{cases}$$

$t\rightarrow\omega$

$\vec{\mathbf{f}}(x,y,z,t)\longrightarrow$ **FT** $\longrightarrow\vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial\vec{\mathbf{f}}}{\partial t}\longrightarrow$ **FT** $\longrightarrow j\omega\vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla\cdot\vec{\mathbf{f}}\longrightarrow$ **FT** $\longrightarrow\nabla\cdot\vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla\times\vec{\mathbf{f}}\longrightarrow$ **FT** $\longrightarrow\nabla\times\vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)\longrightarrow$ **FT** $\longrightarrow\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

$\nabla\cdot\vec{\mathbf{d}}(\vec{\mathbf{r}},t)\longrightarrow$ **FT** $\longrightarrow\nabla\cdot\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

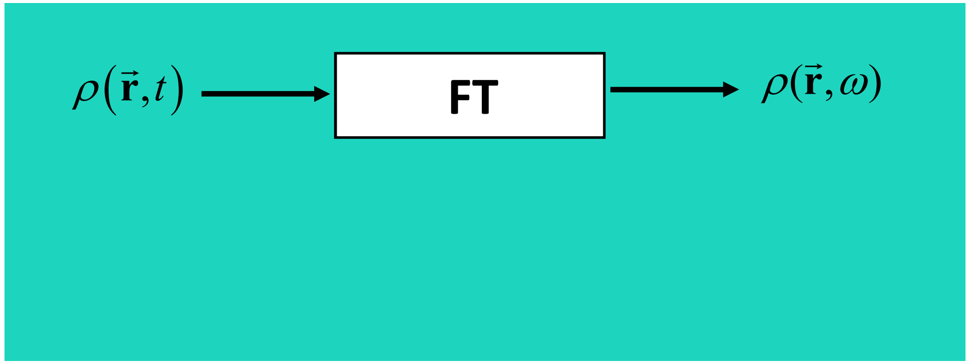
Time domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \rightarrow \omega$

Frequency domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\
\nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\
\nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)
\end{cases}
$$



Maxwell equations
Time domain & Frequency domain

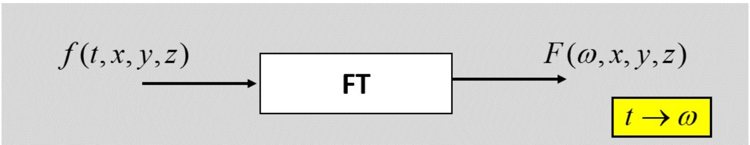
Time domain

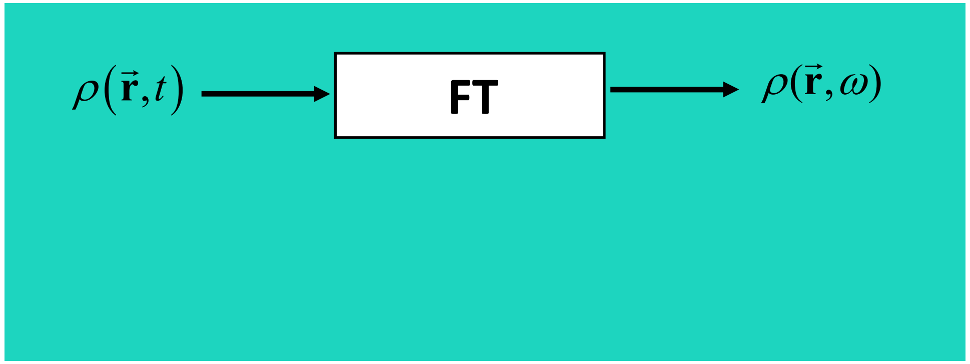
$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \end{cases}$$





Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \end{cases}$$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$ $\quad t \rightarrow \omega$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ FT $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ FT $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{b}}(\vec{\mathbf{r}},t) \longrightarrow$ FT $\longrightarrow \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \to \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \end{cases}$$

$t \to \omega$

$\vec{\mathbf{f}}(x,y,z,t) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{F}}(x,y,z,\omega)$

$\dfrac{\partial \vec{\mathbf{f}}}{\partial t} \longrightarrow$ **FT** $\longrightarrow j\omega \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \cdot \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$

$\nabla \times \vec{\mathbf{f}} \longrightarrow$ **FT** $\longrightarrow \nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

$\vec{\mathbf{b}}(\vec{\mathbf{r}},t) \longrightarrow$ **FT** $\longrightarrow \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$

$\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) \longrightarrow$ **FT** $\longrightarrow \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\
\nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\
\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0
\end{cases}
$$

$t \rightarrow \omega$

Frequency domain

$$
\begin{cases}
\nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\
\nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\
\nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\
\nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)
\end{cases}
$$

$t \rightarrow \omega$

- $\vec{\mathbf{f}}(x,y,z,t)$ → FT → $\vec{\mathbf{F}}(x,y,z,\omega)$
- $\dfrac{\partial \vec{\mathbf{f}}}{\partial t}$ → FT → $j\omega \vec{\mathbf{F}}(x,y,z,\omega)$
- $\nabla \cdot \vec{\mathbf{f}}$ → FT → $\nabla \cdot \vec{\mathbf{F}}(x,y,z,\omega)$
- $\nabla \times \vec{\mathbf{f}}$ → FT → $\nabla \times \vec{\mathbf{F}}(x,y,z,\omega)$

- $\vec{\mathbf{b}}(\vec{\mathbf{r}},t)$ → FT → $\vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$
- $\nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t)$ → FT → $\nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

Maxwell equations
Time domain & Frequency domain

Time domain		Frequency domain
$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$	$t \rightarrow \omega$	$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t)$	Volt/m
$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$	Coulomb/m^2
$\vec{\mathbf{h}}(\vec{\mathbf{r}},t)$	Ampere/m
$\vec{\mathbf{b}}(\vec{\mathbf{r}},t)$	Weber/m^2
$\vec{\mathbf{j}}(\vec{\mathbf{r}},t)$	Ampere/m^2
$\rho(\vec{\mathbf{r}},t)$	Coulomb/m^3

Maxwell equations
Time domain & Frequency domain

Time domain		Frequency domain
$$\begin{cases} \nabla\times\vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial\vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla\times\vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial\vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla\cdot\vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla\cdot\vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$	$t \rightarrow \omega$	$$\begin{cases} \nabla\times\vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega\vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla\times\vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla\cdot\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla\cdot\vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t)$	Volt/m	$\vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$
$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$	Coulomb/m^2	$\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$
$\vec{\mathbf{h}}(\vec{\mathbf{r}},t)$	Ampere/m	$\vec{\mathbf{H}}(\vec{\mathbf{r}},\omega)$
$\vec{\mathbf{b}}(\vec{\mathbf{r}},t)$	Weber/m^2	$\vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$
$\vec{\mathbf{j}}(\vec{\mathbf{r}},t)$	Ampere/m^2	$\vec{\mathbf{J}}(\vec{\mathbf{r}},\omega)$
$\rho(\vec{\mathbf{r}},t)$	Coulomb/m^3	$\rho(\vec{\mathbf{r}},\omega)$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

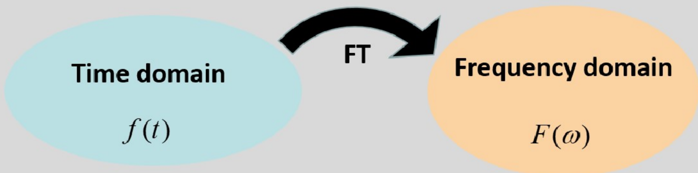
Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t)$	Volt/m
$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$	Coulomb/m^2
$\vec{\mathbf{h}}(\vec{\mathbf{r}},t)$	Ampere/m
$\vec{\mathbf{b}}(\vec{\mathbf{r}},t)$	Weber/m^2
$\vec{\mathbf{j}}(\vec{\mathbf{r}},t)$	Ampere/m^2
$\rho(\vec{\mathbf{r}},t)$	Coulomb/m^3

$\vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$

..memo



$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-j\omega t} dt$ **Fourier Transform (FT)**

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

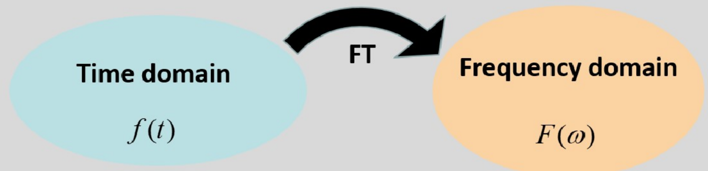
Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t)$	Volt/m
$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$	Coulomb/m^2
$\vec{\mathbf{h}}(\vec{\mathbf{r}},t)$	Ampere/m
$\vec{\mathbf{b}}(\vec{\mathbf{r}},t)$	Weber/m^2
$\vec{\mathbf{j}}(\vec{\mathbf{r}},t)$	Ampere/m^2
$\rho(\vec{\mathbf{r}},t)$	Coulomb/m^3

$\vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$ (Volt x s) /m

..memo



$$F(\omega) = \int_{-\infty}^{+\infty} f(t) e^{-j\omega t} dt$$

Fourier Transform (FT)

Maxwell equations
Time domain & Frequency domain

Time domain		Frequency domain
$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$	$t \rightarrow \omega$	$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$

$\vec{\mathbf{e}}(\vec{\mathbf{r}},t)$	Volt/m	$\vec{\mathbf{E}}(\vec{\mathbf{r}},\omega)$	(Volt x s) /m
$\vec{\mathbf{d}}(\vec{\mathbf{r}},t)$	Coulomb/m^2	$\vec{\mathbf{D}}(\vec{\mathbf{r}},\omega)$	(Coulomb x s)/m^2
$\vec{\mathbf{h}}(\vec{\mathbf{r}},t)$	Ampere/m	$\vec{\mathbf{H}}(\vec{\mathbf{r}},\omega)$	(Ampere x s)/m
$\vec{\mathbf{b}}(\vec{\mathbf{r}},t)$	Weber/m^2	$\vec{\mathbf{B}}(\vec{\mathbf{r}},\omega)$	(Weber x s)/m^2
$\vec{\mathbf{j}}(\vec{\mathbf{r}},t)$	Ampere/m^2	$\vec{\mathbf{J}}(\vec{\mathbf{r}},\omega)$	(Ampere x s)/m^2
$\rho(\vec{\mathbf{r}},t)$	Coulomb/m^3	$\rho(\vec{\mathbf{r}},\omega)$	(Coulomb x s)/m^3

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$$\frac{\partial \rho(\vec{\mathbf{r}},t)}{\partial t} + \nabla \cdot \vec{\mathbf{j}}(\vec{\mathbf{r}},t) = 0$$

$$t \rightarrow \omega$$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

Maxwell equations
Time domain & Frequency domain

Time domain

$$\begin{cases} \nabla \times \vec{\mathbf{e}}(\vec{\mathbf{r}},t) = -\dfrac{\partial \vec{\mathbf{b}}(\vec{\mathbf{r}},t)}{\partial t} \\ \nabla \times \vec{\mathbf{h}}(\vec{\mathbf{r}},t) = \dfrac{\partial \vec{\mathbf{d}}(\vec{\mathbf{r}},t)}{\partial t} + \vec{\mathbf{j}}(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{d}}(\vec{\mathbf{r}},t) = \rho(\vec{\mathbf{r}},t) \\ \nabla \cdot \vec{\mathbf{b}}(\vec{\mathbf{r}},t) = 0 \end{cases}$$

$$\frac{\partial \rho(\vec{\mathbf{r}},t)}{\partial t} + \nabla \cdot \vec{\mathbf{j}}(\vec{\mathbf{r}},t) = 0$$

$t \rightarrow \omega$

Frequency domain

$$\begin{cases} \nabla \times \vec{\mathbf{E}}(\vec{\mathbf{r}},\omega) = -j\omega \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) \\ \nabla \times \vec{\mathbf{H}}(\vec{\mathbf{r}},\omega) = j\omega \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) + \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{D}}(\vec{\mathbf{r}},\omega) = \rho(\vec{\mathbf{r}},\omega) \\ \nabla \cdot \vec{\mathbf{B}}(\vec{\mathbf{r}},\omega) = 0 \end{cases}$$

$$j\omega\rho(\vec{\mathbf{r}},\omega) + \nabla \cdot \vec{\mathbf{J}}(\vec{\mathbf{r}},\omega) = 0$$

Maxwell equations
Time domain & Phasors

Phasors

Time domain

$f(t)$

Phasors

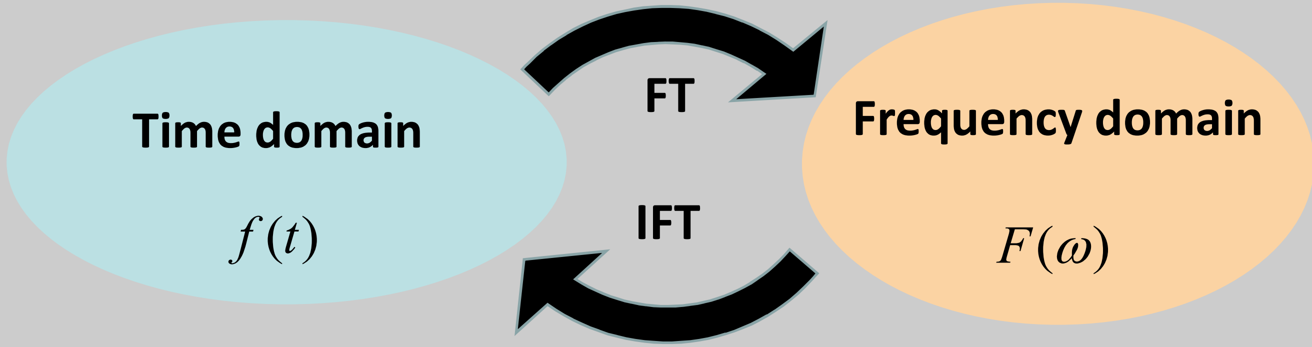
Time domain

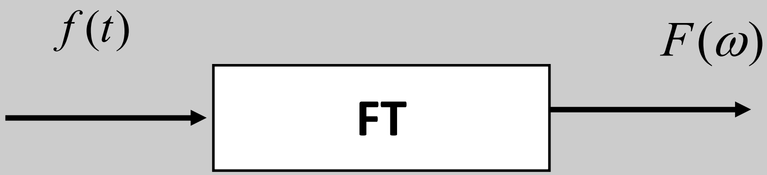
$f(t)$

Signals usually adopted in ICT applications

$$f(t) = A(t)\cos\left(2\pi f_0 t + \alpha(t)\right)$$

….. Memo ….





$$F(\omega) = \int_{-\infty}^{+\infty} f(t)\, e^{-j\omega t}\, dt$$

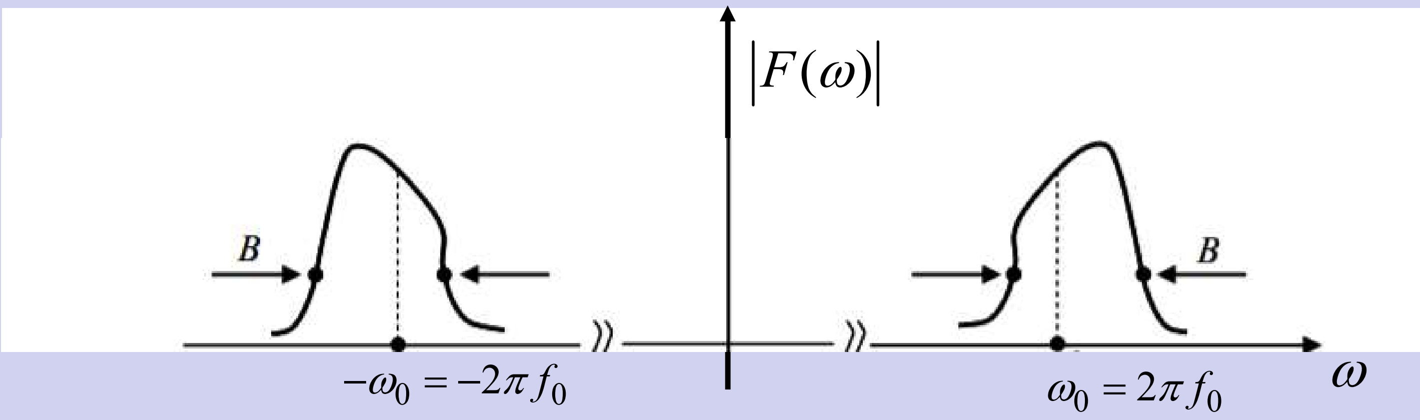
$$f(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} F(\omega)\, e^{j\omega t}\, d\omega =$$

$$= \frac{1}{2\pi} \left[\int_{-\infty}^{+\infty} F(\omega) \cos(\omega t)\, d\omega + j \int_{-\infty}^{+\infty} F(\omega) \sin(\omega t)\, d\omega \right]$$

Bandwidth

$$F(\omega) = \int_{-\infty}^{+\infty} f(t)\, e^{-j\omega t}\, dt$$

$$f(t) = \frac{1}{2\pi}\left[\int_{-\infty}^{+\infty} F(\omega)\cos(\omega t)\, d\omega + j\int_{-\infty}^{+\infty} F(\omega)\sin(\omega t)\, d\omega\right]$$



Phasors

Time domain

$f(t)$

Signals usually adopted in ICT applications

$$f(t) = A(t)\cos\left(2\pi f_0 t + \alpha(t)\right)$$

Phasors

Time domain

$f(t)$

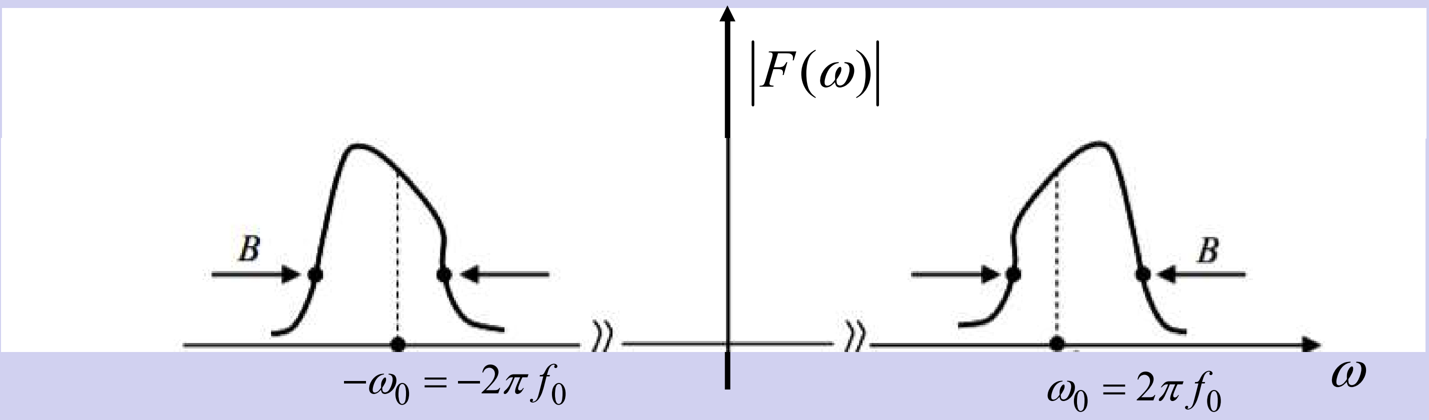
Signals usually analyzed in ICT applications

$$f(t) = A\cos\left(2\pi f_0 t + \alpha\right)$$

Bandwidth

$f(t)$ → **FT** → $F(\omega)=\int_{-\infty}^{+\infty} f(t)\,e^{-j\omega t}\,dt$

$$f(t)=\frac{1}{2\pi}\left[\int_{-\infty}^{+\infty} F(\omega)\cos(\omega t)\,d\omega + j\int_{-\infty}^{+\infty} F(\omega)\sin(\omega t)\,d\omega\right]$$

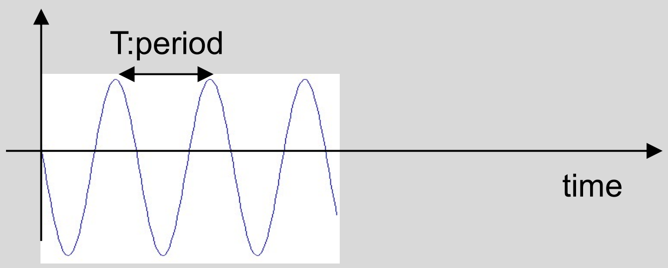


Phasors

Time domain

$f(t)$

Signals usually adopted in ICT applications



$$f(t) = A\cos\left(2\pi f_0 t + \alpha\right)$$

$$f_0 : frequency = \frac{1}{T}$$

$$\omega_0 : angular\ frequency = 2\pi f_0$$

Phasors

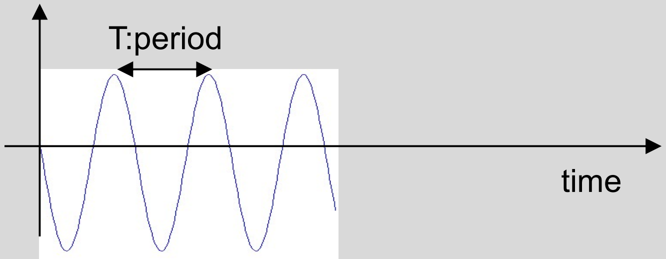
Time domain

$f(t) = A\cos(\omega_0 t + \alpha)$

Phasor domain

?

Signals usually adopted in ICT applications



$$f(t) = A\cos(2\pi f_0 t + \alpha)$$

$$f_0 : frequency = \frac{1}{T}$$

$$\omega_0 : angular\ frequency = 2\pi f_0$$

Phasors

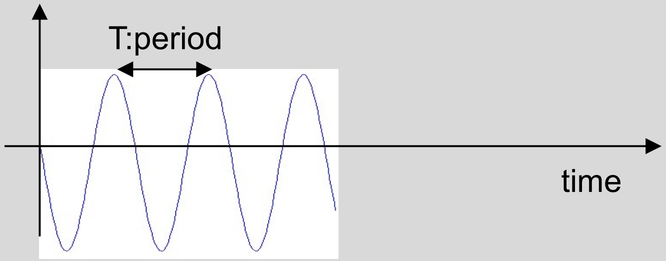
Time domain

$$f(t) = A\cos(\omega_0 t + \alpha)$$

Phasor domain

$$F = Ae^{j\alpha}$$

Signals usually adopted in ICT applications



$$f(t) = A\cos(2\pi f_0 t + \alpha)$$

$$f_0 : frequency = \frac{1}{T}$$

$$\omega_0 : angular\ frequency = 2\pi f_0$$

Phasors

Time domain

$$f(t) = A\cos(\omega_0 t + \alpha)$$

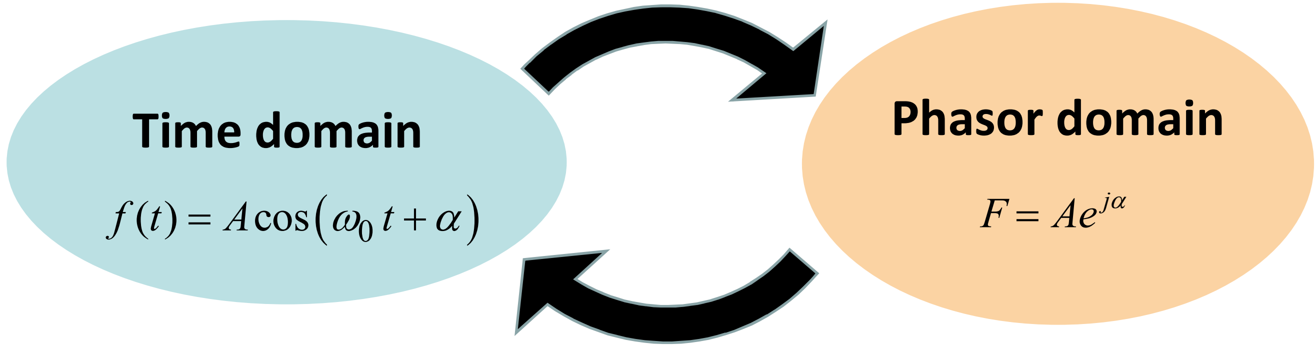
Phasor domain

$$F = Ae^{j\alpha}$$

1) How to jump back from the Phasor domain to the Time domain

2) Time domain derivative and Phasors

Phasors



1) How to jump back from the Phasor domain to the Time domain

Phasors

Time domain

$$f(t) = A\cos(\omega_0 t + \alpha)$$

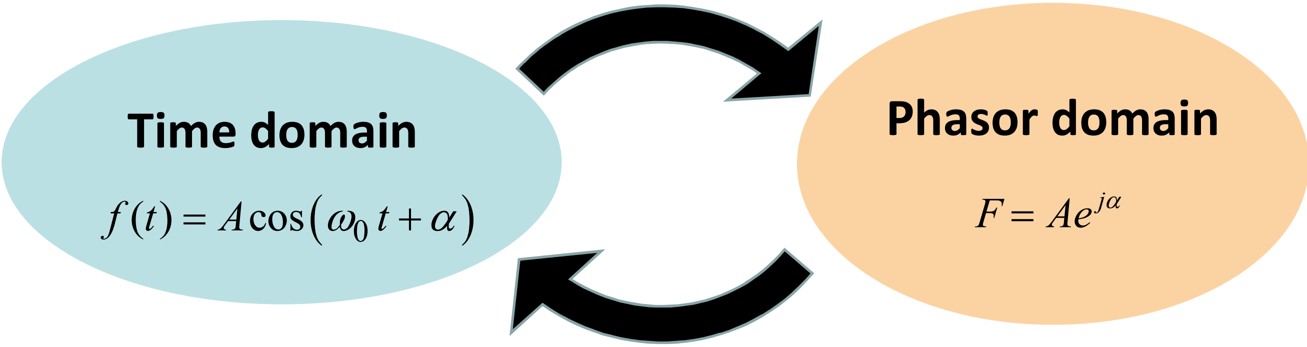
Phasor domain

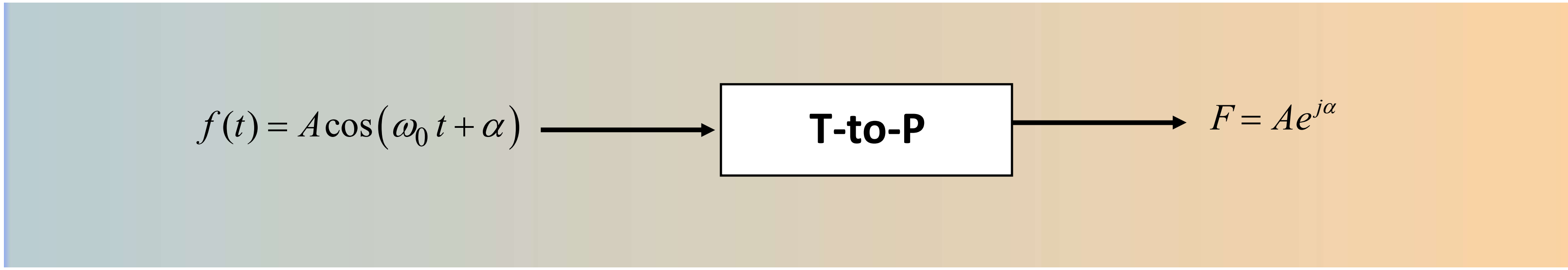
$$F = Ae^{j\alpha}$$

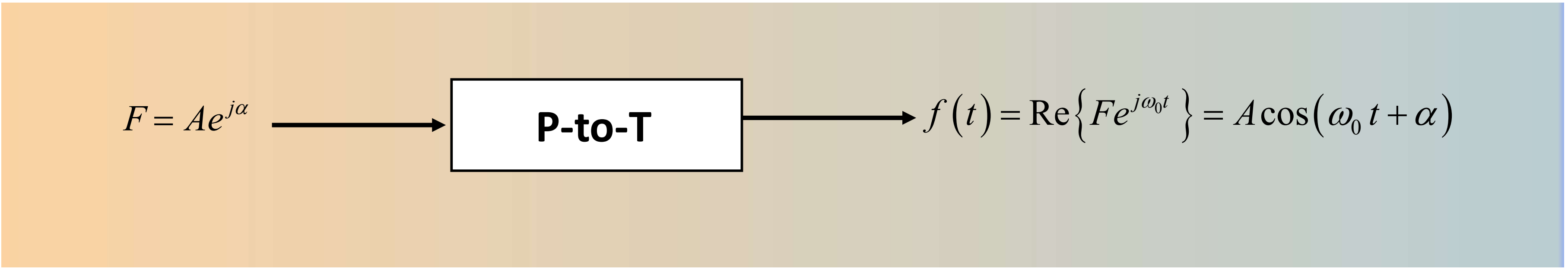
1) How to jump back from the Phasor domain to the Time domain

$$f(t) = \mathrm{Re}\left\{Fe^{j\omega_0 t}\right\} = \mathrm{Re}\left\{Ae^{j\alpha}e^{j\omega_0 t}\right\} = A\cos(\omega_0 t + \alpha)$$

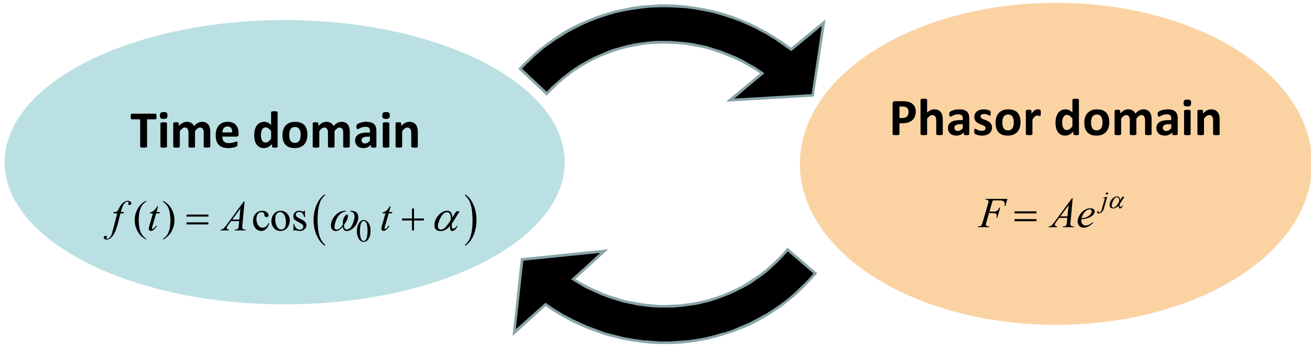
Phasors


Time domain
$f(t) = A\cos(\omega_0 t + \alpha)$
Phasor domain
$F = Ae^{j\alpha}$

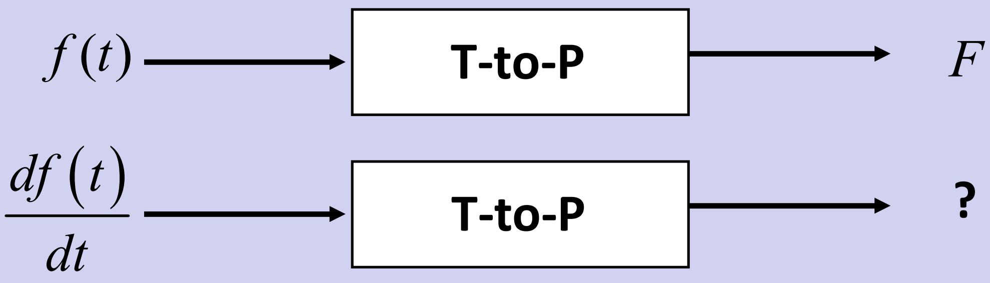

$f(t) = A\cos(\omega_0 t + \alpha)$
T-to-P
$F = Ae^{j\alpha}$


$F = Ae^{j\alpha}$
P-to-T
$f(t) = \mathrm{Re}\{Fe^{j\omega_0 t}\} = A\cos(\omega_0 t + \alpha)$

Phasors



2) Time domain derivative and Phasors



Phasors

Time domain

$$f(t) = A\cos(\omega_0 t + \alpha)$$

Phasor domain

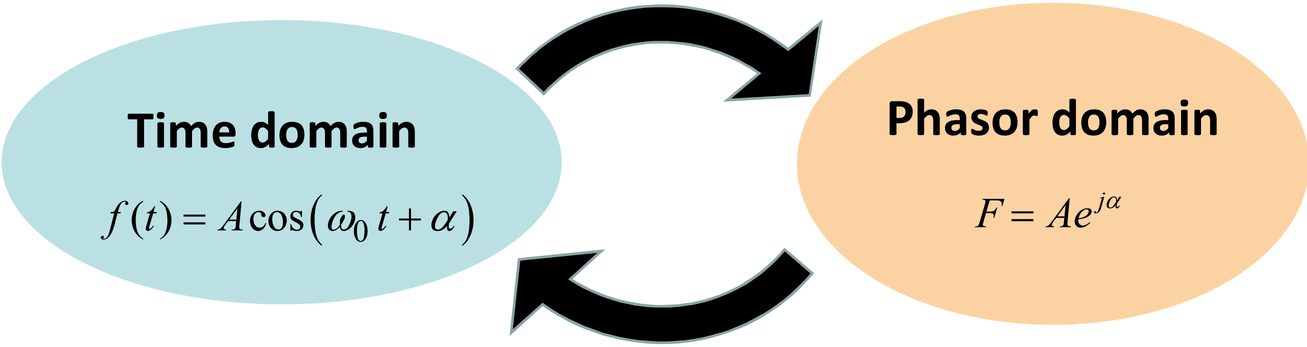
$$F = Ae^{j\alpha}$$

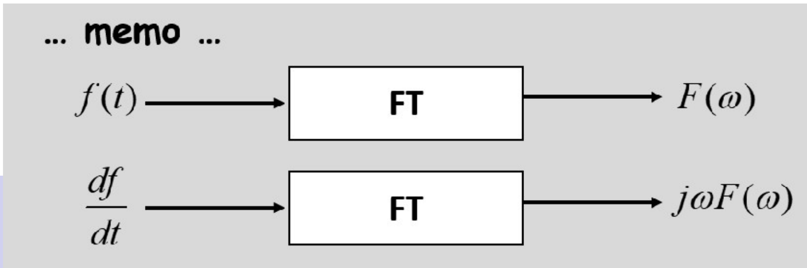
2) Time domain derivative and Phasors

$f(t)$ → **T-to-P** → F

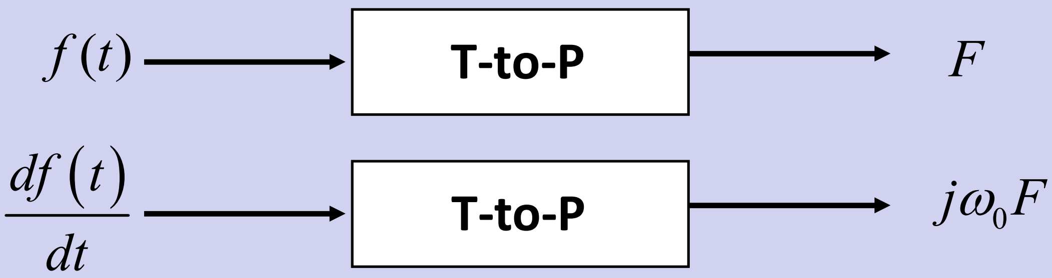
$\dfrac{df(t)}{dt}$ → **T-to-P** → $j\omega_0 F$

Phasors

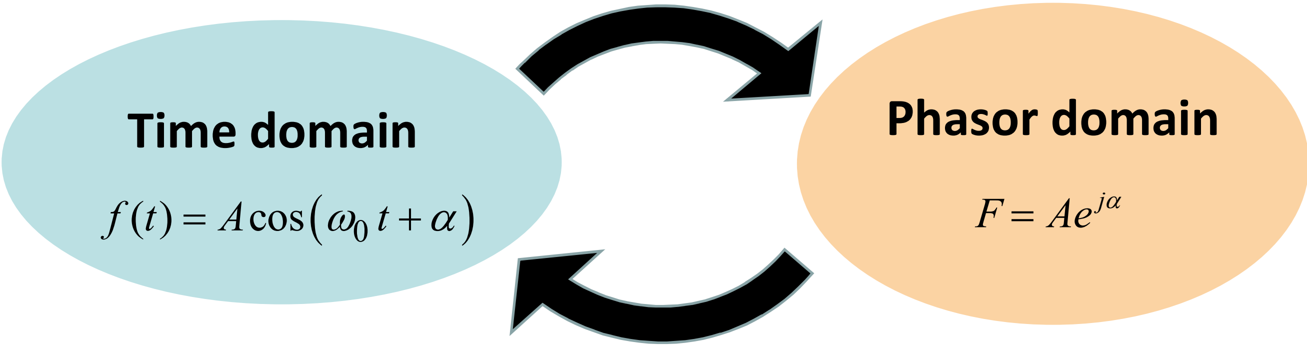




2) Time domain derivative and Phasors



Phasors



... memo ...

$f(t) \longrightarrow$ **FT** $\longrightarrow F(\omega)$

$\frac{df}{dt} \longrightarrow$ **FT** $\longrightarrow j\omega F(\omega)$

2) Time domain derivative and Phasors

$f(t) \longrightarrow$ **T-to-P** $\longrightarrow F$

$\frac{df(t)}{dt} \longrightarrow$ **T-to-P** $\longrightarrow j\omega_0 F$

ω_0 now is fixed!