# Magnetic diagnostics

# Magnetic diagnostics

Magnetic diagnostics are instrumentations used for measurements of:
- **magnetic fields** outside the plasma
- **electric currents** that are the source of the magnetic fields

Magnetics measurements are crucial in fusion devices for:
- **Machine protection and basic control:** ‘plasma current’, ‘plasma position’, ‘plasma shape’, ‘magnetic field errors’, ‘halo currents’
- **Advanced plasma control:** ‘Plasma current profile’, ‘equilibrium magnetic field distribution’
- **Physic studies and performance evaluation:** ‘High frequency MHD instabilities’

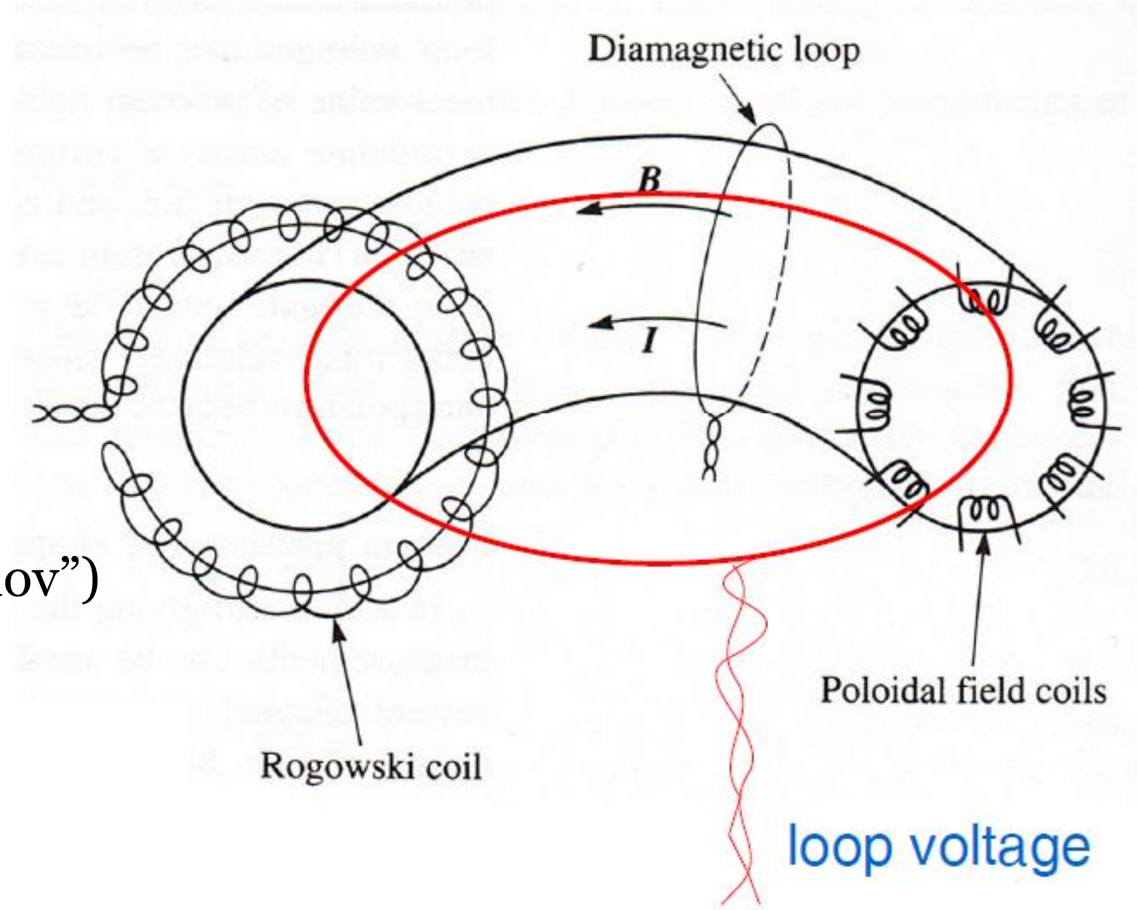
# Magnetic diagnostics

**Measurements**

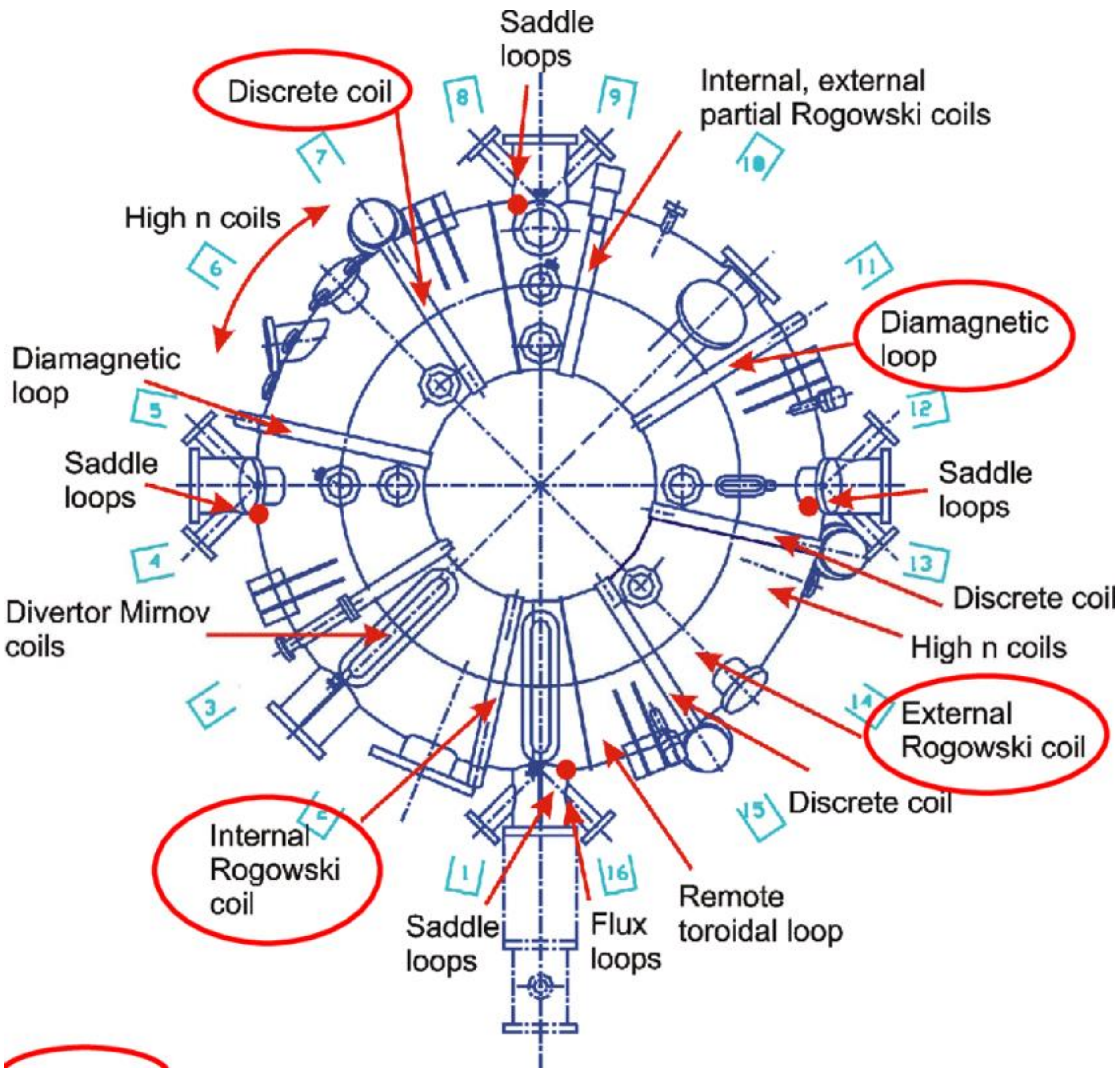
- ❑ Toroidal magnetic field
- ❑ Poloidal magnetic field
- ❑ Plasma current
- ❑ MHD instabilities
- ❑ Loop voltage.
- ❑ Plasma Energy

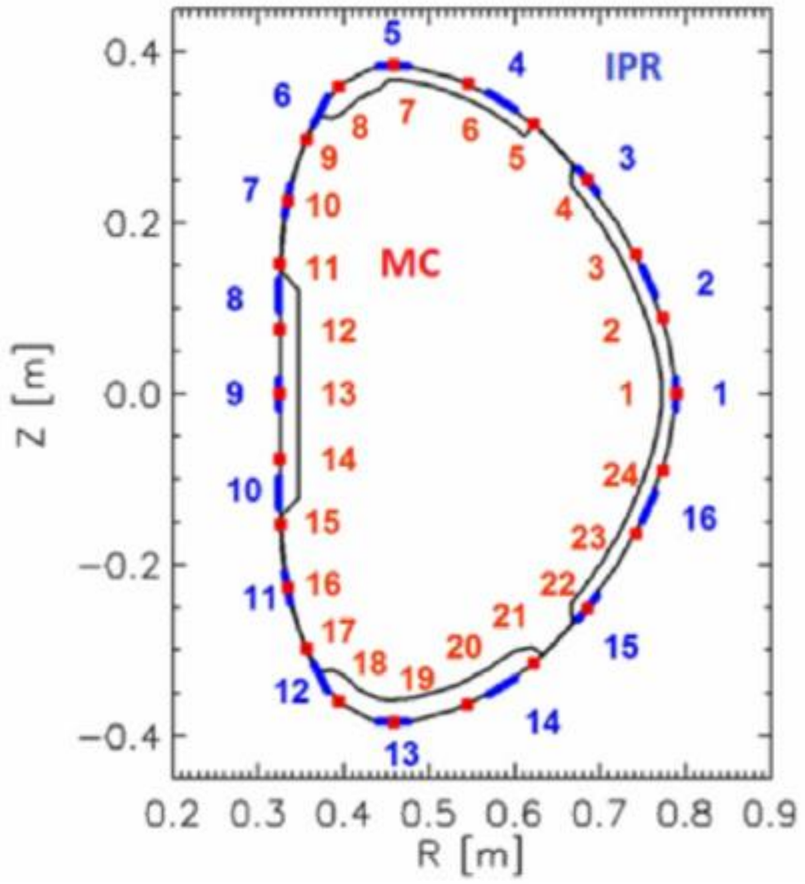
**Magnetic sensors**:

- ❖ Inductive
  - ➢ Diamagnetic loop
  - ➢ Magnetic field probes ("pick-up" or "Mirnov")
  - ➢ Rogowsky coils
  - ➢ Saddle loops
  - ➢ Flux loops
- ❖ Steady-state
  - ➢ Hall probes
  - ➢ Resistive shunt



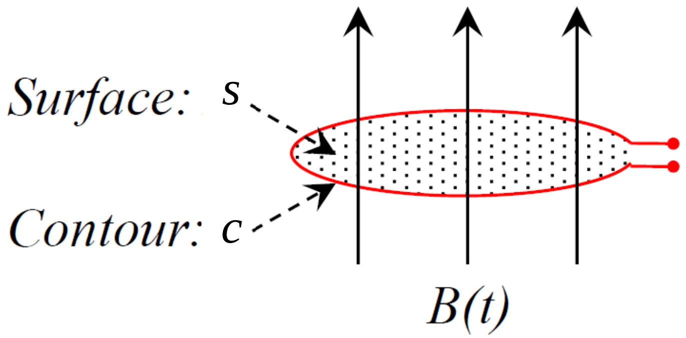
# Magnetic diagnostics



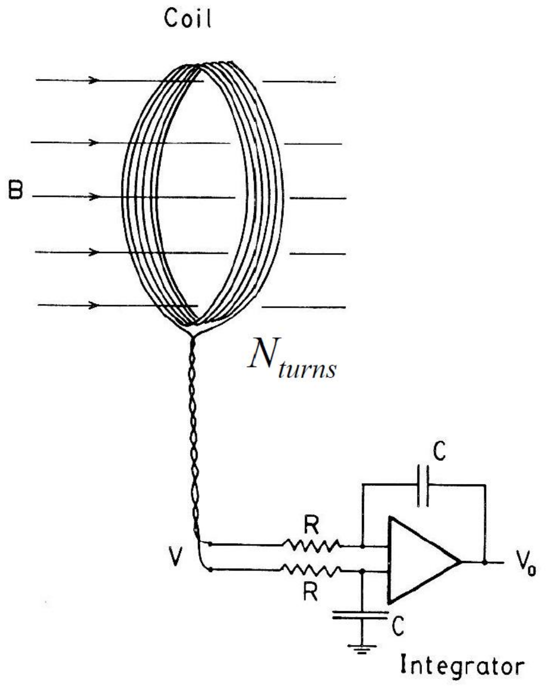

Red — Mirnov coils (MC), blue — internal partial Rogowski (IPR) coils.

# Magnetic field measurements




$$\nabla \times \overline{E} = -\frac{\partial \overline{B}}{\partial t}$$

$$f.e.m.i = \oint_C \overline{E} \cdot d\overline{l} = -\int_S \frac{\partial \overline{B}}{\partial t} \cdot d\overline{s} = -\frac{d\Phi_c}{dt}$$

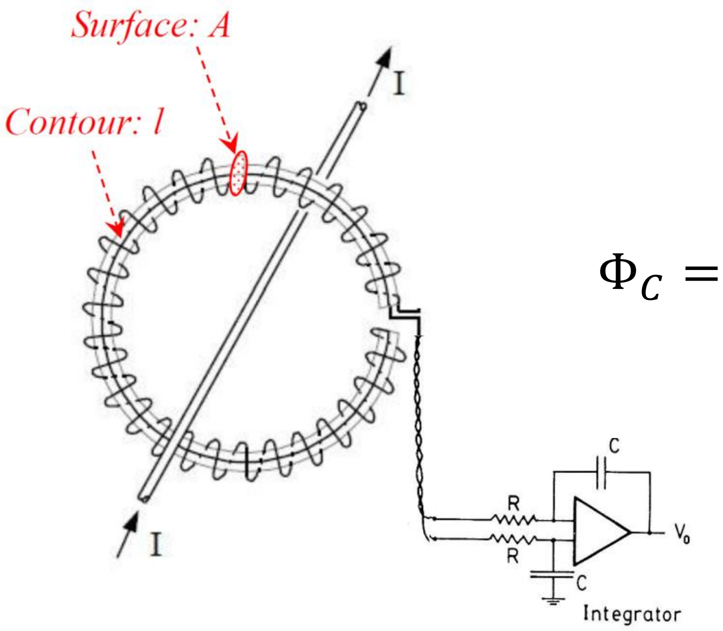



$$\Delta V = \int_S \frac{\partial \overline{B}}{\partial t} \cdot d\overline{s} = \mathrm{NS}\frac{\partial \overline{B} \cdot \overline{n}}{\partial t} \rightarrow \int_0^t V(t) = \mathrm{NS}\,\overline{B} \cdot \overline{n}$$

$$\overline{B} \cdot \overline{n} = \frac{1}{NS}\mathrm{RC} \cdot V(t)$$

- Diamagnetic loop
- Magnetic field probes (“pick-up” or “Mirnov”)
- Saddle loops

# Plasma current measurements




$$\nabla \times \overline{H} = \overline{J}$$

$$\oint_C \overline{H} \cdot d\overline{l} = \int_S \overline{J} \cdot d\overline{s} = I$$

$$\Phi_C = n \oint_l \left[ \int_A \overline{B} \cdot d\overline{A} \right] \cdot dl$$

*n*= number of wire for unit length

$$\Phi_C = n \oint_l \left[ \int_A \overline{B} \cdot d\overline{A} \right] \cdot dl = n \int_A \mu_0 \left[ \oint_l \overline{H} \cdot dl \right] \cdot d\overline{A} = n \int_A \mu_0 [I] \cdot d\overline{A} = n\mu_0 IA$$

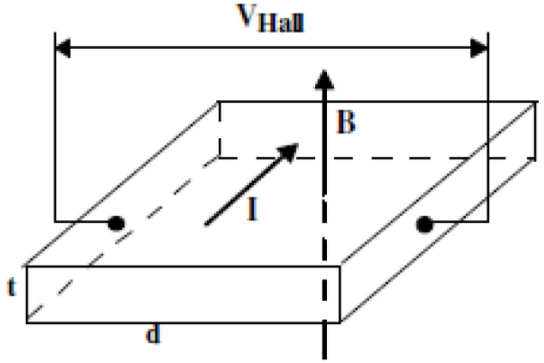
$$V(t) = -\frac{d\Phi_C}{dt}$$

$$\boxed{V(t) = -n\mu_0 A \frac{dI}{dt}}$$

$$V_0 = \frac{n\mu_0 A}{RC} I \qquad I = \frac{RC}{n\mu_0 A} V_0$$

# Plasma current measurements

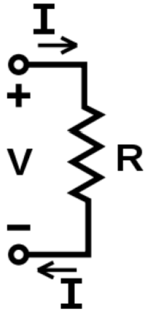
Concept based on Hall effect in semiconductors or metals:




$$V_{Hall} = \frac{IB}{qnt}$$

$q$ = charge carrier
$n$ = charge carrier density
$t$ = sensor thickness

Concept of resistive shunts based on Ohm's law:




$$V = RI$$

Both methos do not need an integration stage

# Magnetic measurements

**Measurements**

- Toroidal magnetic field → diamagnetic loops, poloidal flux loops, pick up coils
- Poloidal magnetic field → pick up coils and Mirnov coils
- Plasma current → full Rogowski coils
- MHD instabilities ($\frac{dB_{pol}}{dt}$) → Sadde coils
- Loop voltage → toroidal loop flux
- Eddy current → partial Rogowski coils

# Magnetic measurements

Combinations of several measurements, with proper assumptions on plasma model, allow to obtain a number of plasma parameters:

| | Plasma Current | Plasma Position & shape | Plasma Energy | Toroidal EMF | Toroidal Magnetic Field | Scrape Off Layer Current | Coil Current | High-frequency MHD | Low-frequency MHD | halo current |
|---|---|---|---|---|---|---|---|---|---|---|
| Flux loop | | √ | √ | √ | | | | | | |
| Magnetic field probe | √ | √ | √ | | √ | | | √ | √ | |
| Saddle loop | | √ | √ | | | | | | √ | |
| Diamagnetic loop | | | √ | | | | | | | |
| Rogowski coil | √ | | | | | √ | √ | | | √ |
| Resistive shunt | | | | | | √ | | | | √ |
| Hall probe | √ | √ | √ | | √ | | | √ | √ | |