

Calibración de transformadores de corriente

Daniel Slomovitz

Instituto de Ingeniería Eléctrica

Facultad de Ingeniería

UNIVERSIDAD DE LA REPÚBLICA

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Método Diferencial

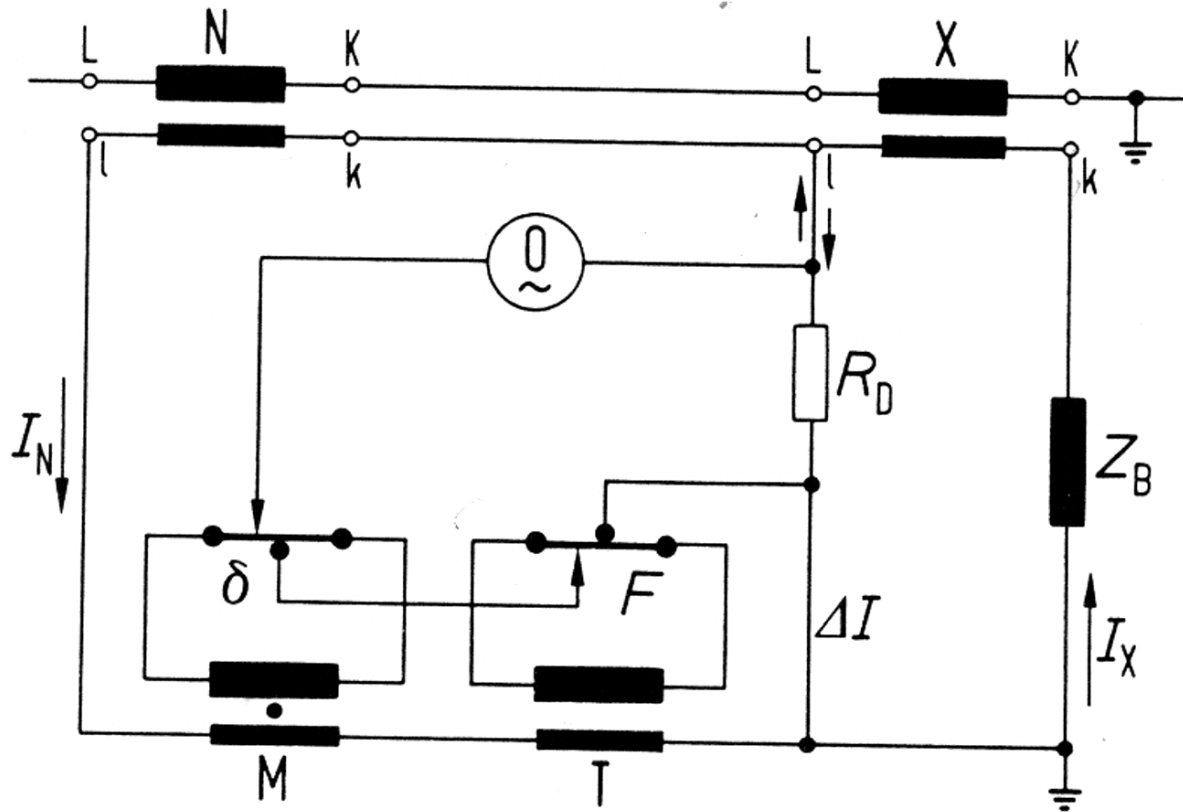
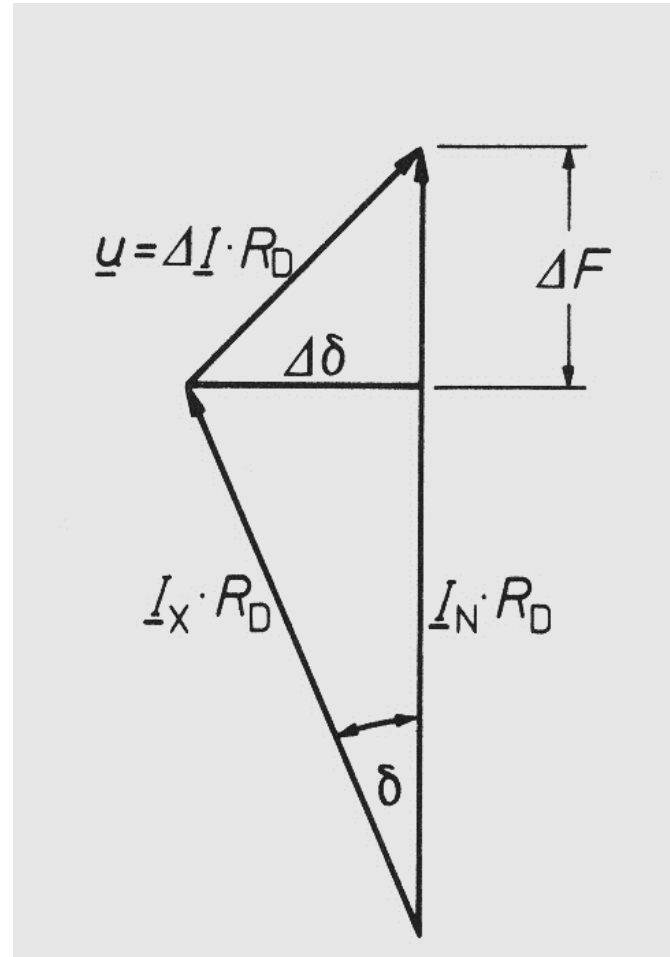


Fig. 11

Diagrama Vectorial



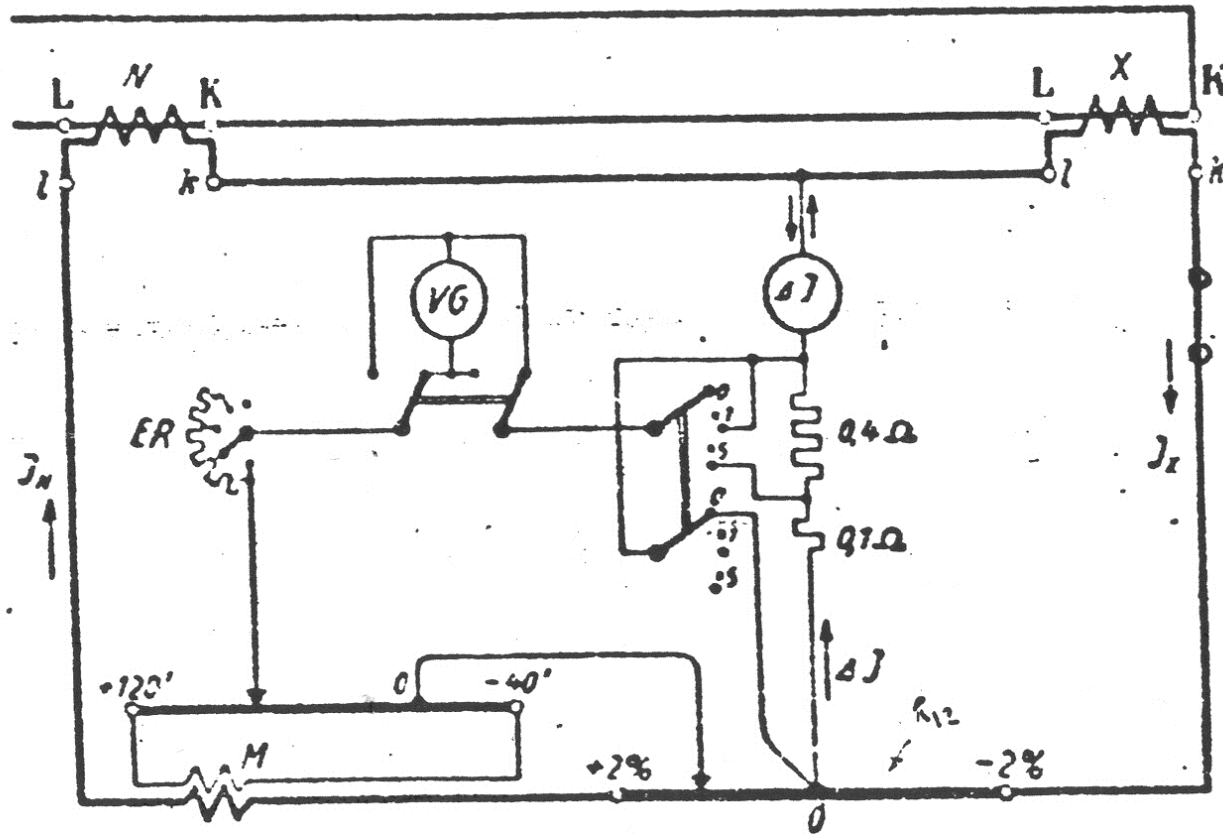
Puente diferencial

Laboratorio de UTE



Puente diferencial

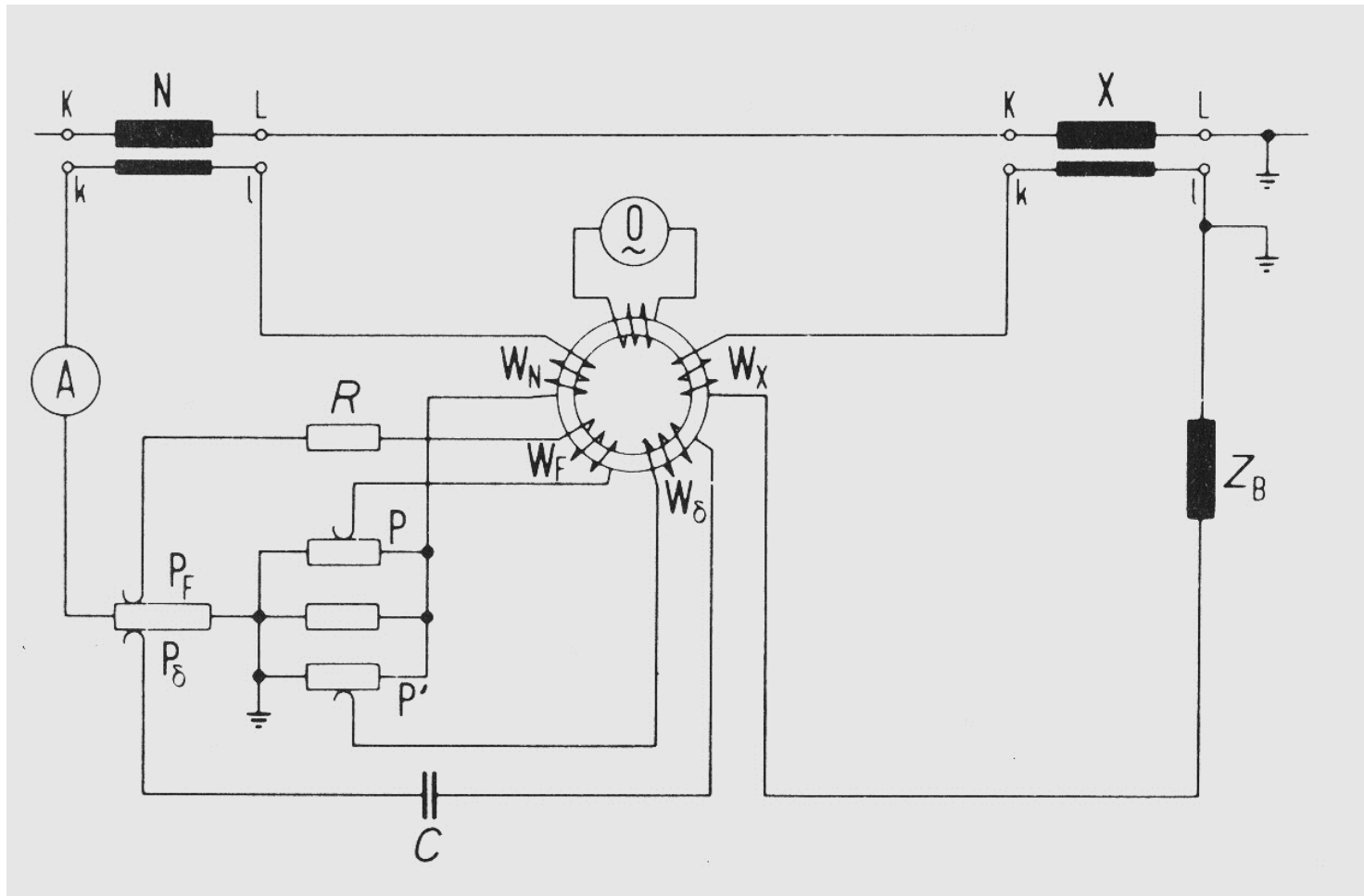
Laboratorio de UTE



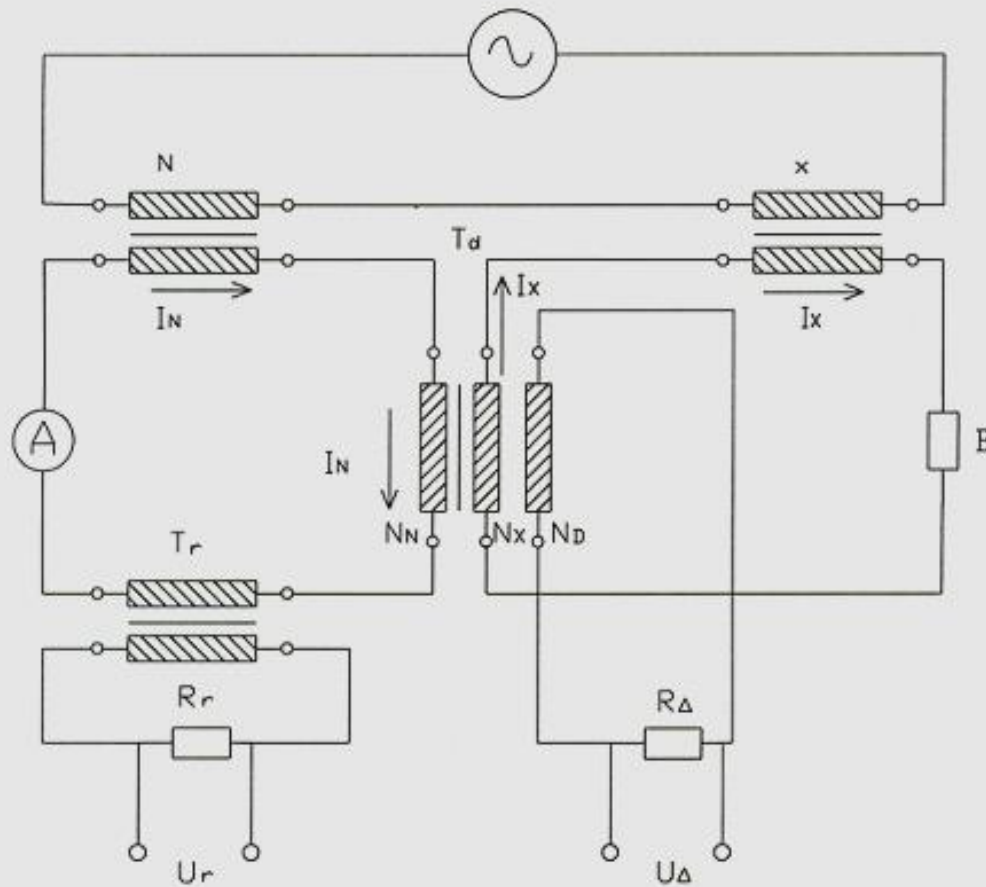
Galvanómetro electrónico



Método con transformador comparador de corriente



Comparador de corriente sin realimentación



$$N_x = N_n \quad I_n ; I_x : 5A$$

$$N_x = 5 N_n \quad I_n = 5A \quad I_x = 1A$$

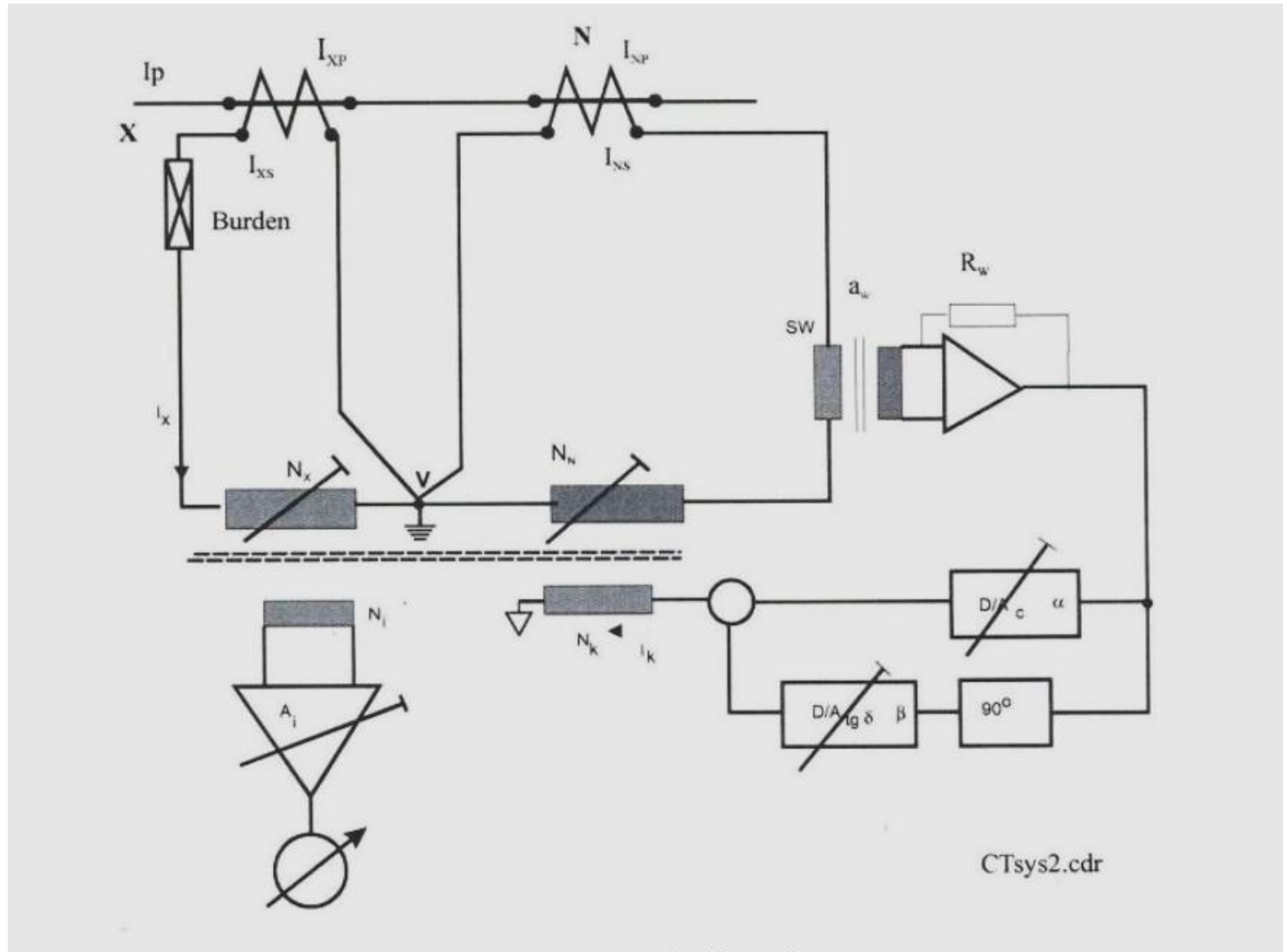
U_r : tensión proporcional a I_n

U_Δ : tensión proporcional a I_x/I_n

Error: proporcional a U_Δ/U_r

Ambas tensiones medidas como fasores (magnitud y fase).

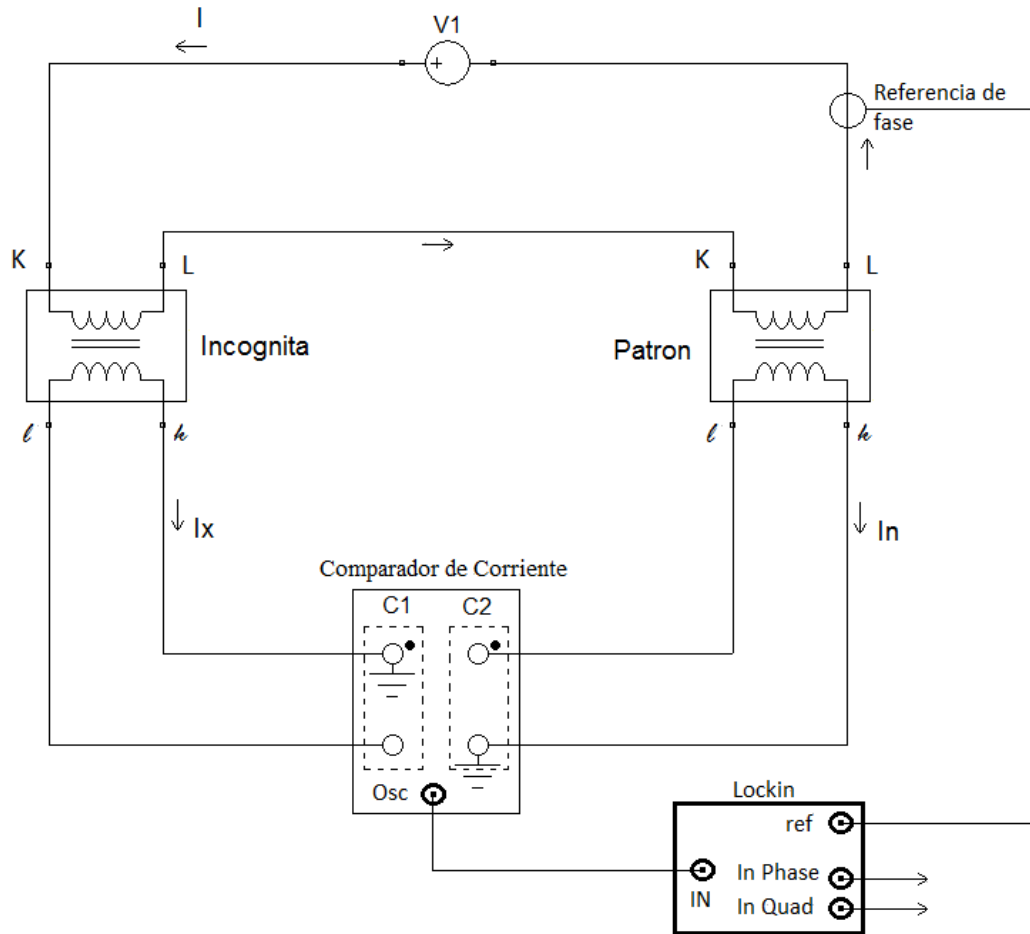
Comparador de corriente con realimentación



Comparador de corriente automático



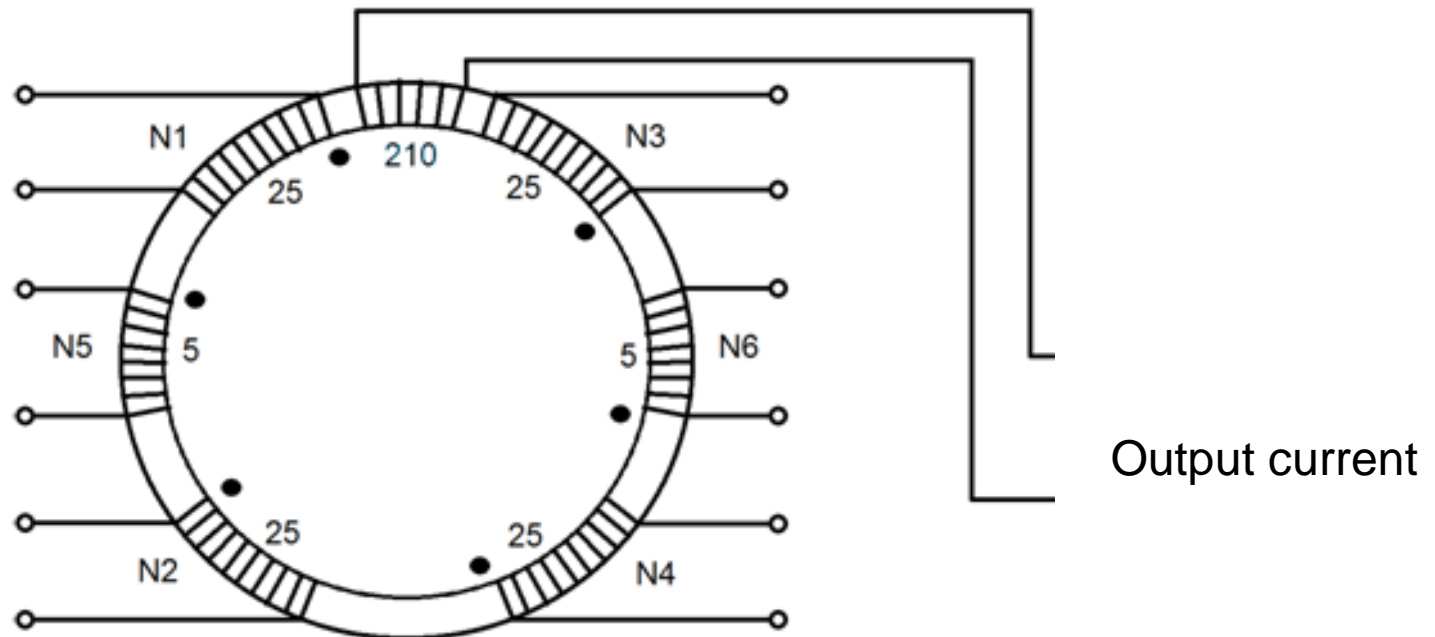
Comparador de corriente sin realimentación



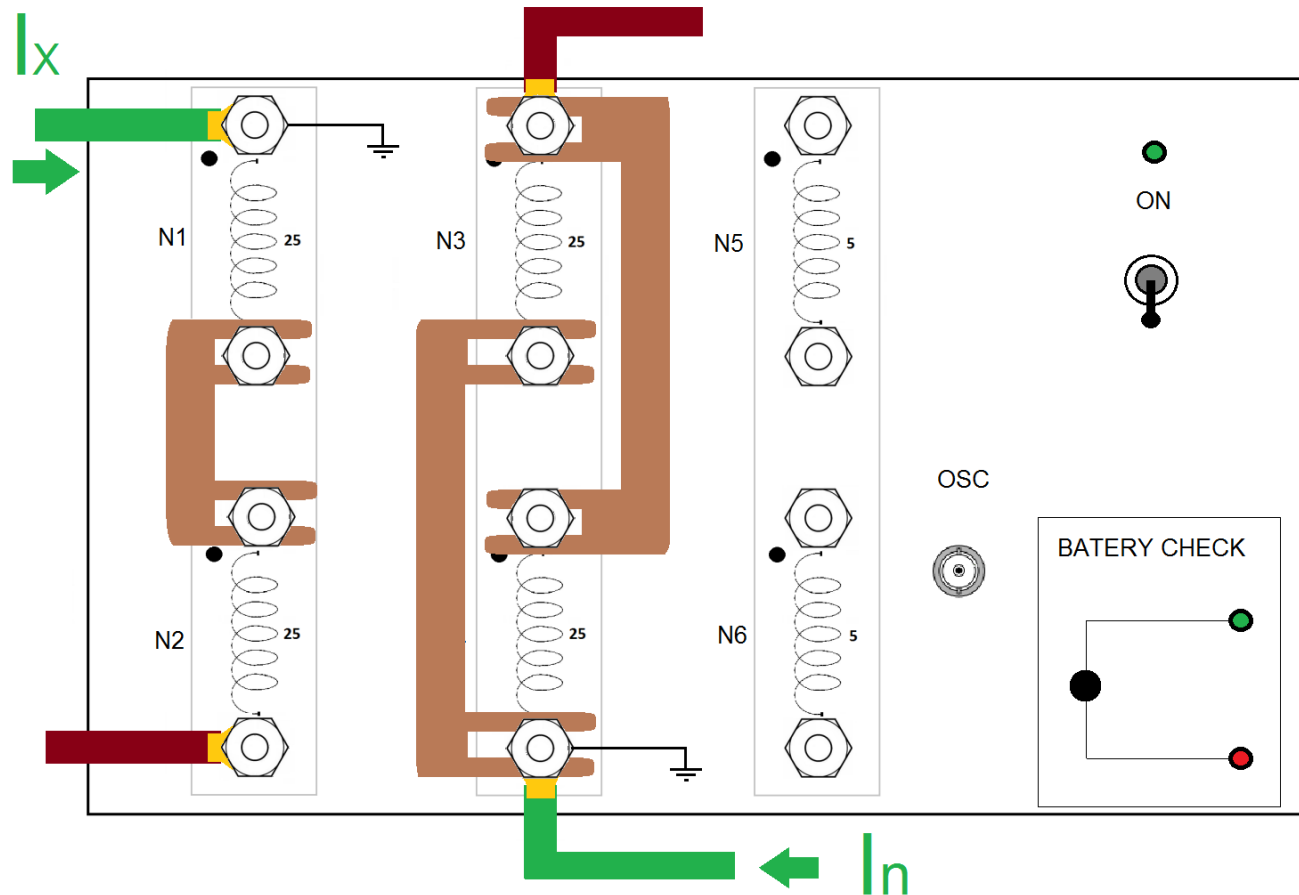
High-Precision Current Comparator for Current Transformer Calibrations, Daniel Slomovitz, Gonzalo Aristoy, Leonardo Trigo, Alejandro Santos, X SEMETRO, 2013.

Comparador de corriente UTE

- Toroidal mu-metal core with 6 identical primary windings (rope type).
- Each winding: 5 x 5 turns.

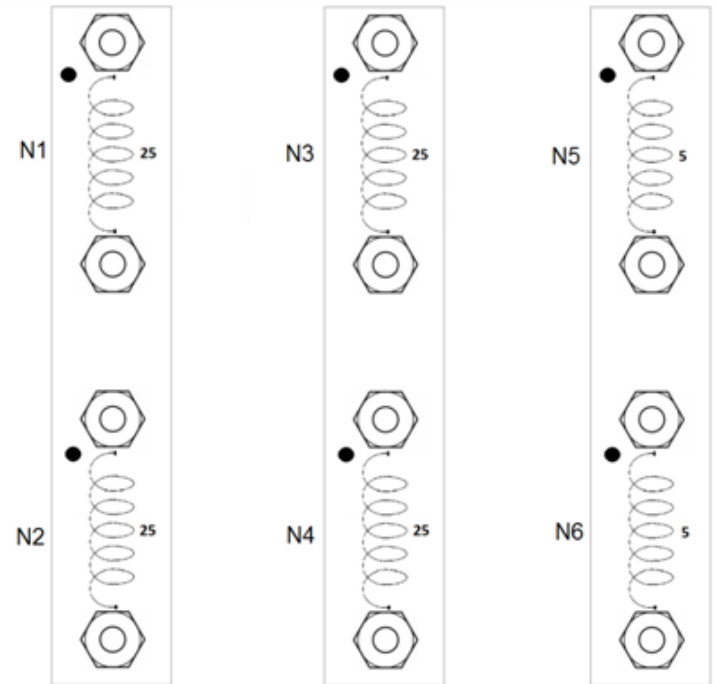


Series-parallel connections

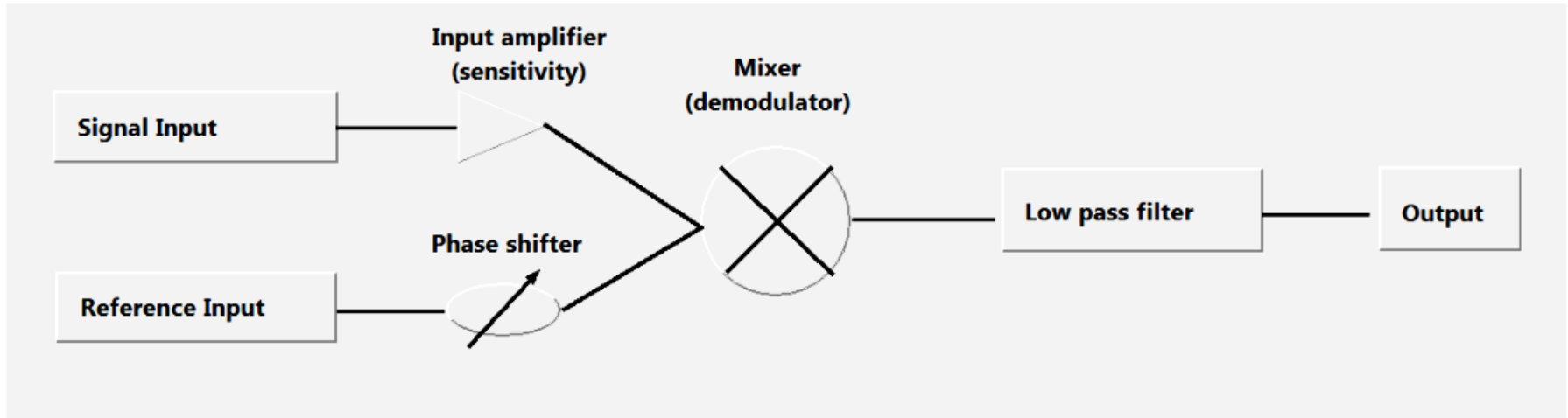


Ratios

Ratio	s: series, p: paralell	Turns
1	N1 s N2 Vs N3 s N4	50 Vs 50
	N1 p N2 Vs N3 p N4	25 Vs 25
2	N1 s N2 Vs N3 p N4	50 Vs 25
	N1 p N2 Vs N3 s N4	25 Vs 50
2.5	N1 p N2 Vs N5 s N6	25 Vs 10
	N3 p N4 Vs N5 s N6	25 Vs 10
5	N1 p N2 Vs N5 p N6	25 Vs 5
	N3 p N4 Vs N5 p N6	25 Vs 5
10	N1 s N2 Vs N5 p N6	50 Vs 5
	N3 s N4 Vs N5 p N6	51 Vs 5

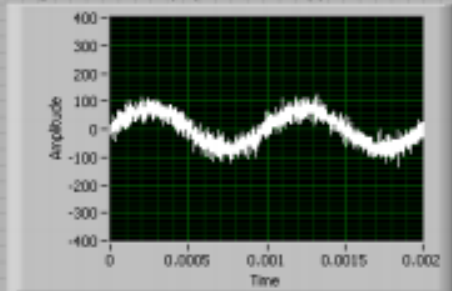


Amplificador Lock-in

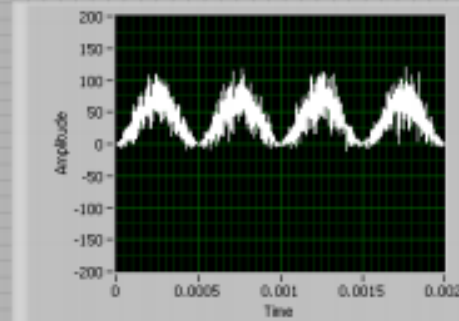


Amplificador Lock-in

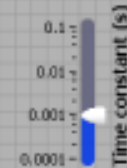
Signal + noise (2 periods only)



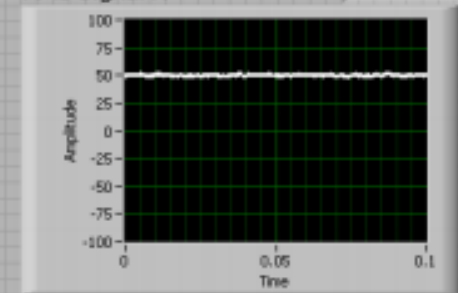
Mixer (Internal, 2 periods)



Low-pass



lockin output (1000 periods)
RMS Signal X



51.66

Note the start at zero has an "artifact" when initialized because the program is not really continuous,

Initialize on start



--and the output time constant's "integration" starts over every loop of the VI

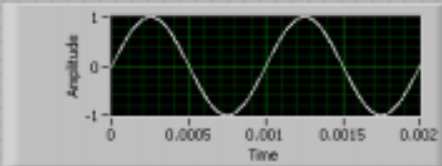
--but! This allows you to see the effect of the time constant on a CHANGING signal, change the time constant!



Control panel for the lock-in amplifier. It includes:

- signal type:
- signal frequency:
- Signal Amplitude RMS:
- Noise Amplitude:
- reference phase adjust (deg):

Reference



Amplificador Lock-in

$$v_s = \sum A_k \cdot \text{sen}(k\omega t + \varphi_k)$$

$$v_r = B \text{sen}(\omega t)$$

$$\frac{1}{T} \int_0^T v_s \cdot v_r dt = \frac{B}{T} \int_0^T \text{sen}(\omega t) \cdot \sum A_k \text{sen}(k\omega t + \varphi_k) dt$$

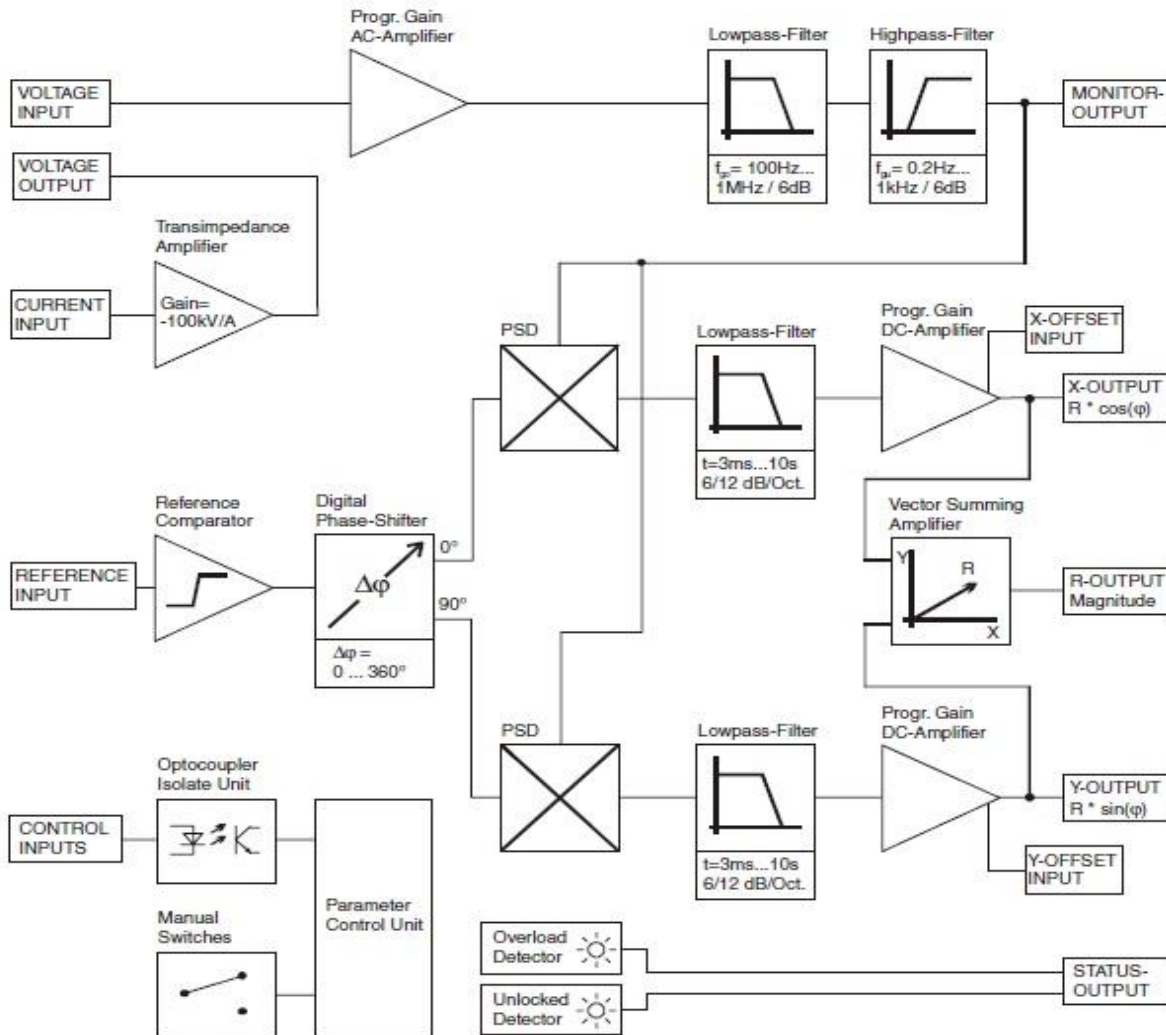
$$= \frac{B}{T} \int_0^T \text{sen}(\omega t) A_1 \underbrace{\text{sen}(\omega t + \varphi_1)}_{\text{sen}(\omega t) \cos(\varphi_1) + \cos(\omega t) \text{sen}(\varphi_1)} dt$$

$$= \frac{B}{T} \int_0^T [\text{sen}^2(\omega t) \cos(\varphi_1) + \underbrace{\text{sen}(\omega t) \cos(\omega t) \text{sen}(\varphi_1)}_{\rightarrow 0}] dt$$

$$= \frac{BA_1}{T} \cos(\varphi_1) \underbrace{\int_0^T \text{sen}^2(\omega t) dt}_{\frac{1}{2} T} = \frac{BA_1}{2} \cos \varphi_1$$

$$T/2 - \text{sen}(2t)/4$$

Amplificador Lock-in comercial



Uncertainty budget

Factor	Contribution $\times 10^{-6}$
Uncertainty type A	0,03
External Magnetic field	0,10
Shunt resistor	0,03
Stray capacitances	0,01
Magnetizing impedance	0,00
Electronic amplifiers	0,02
Multimeters	0,03
Combined unc. $k=2$	0,23

Transformadores patrones

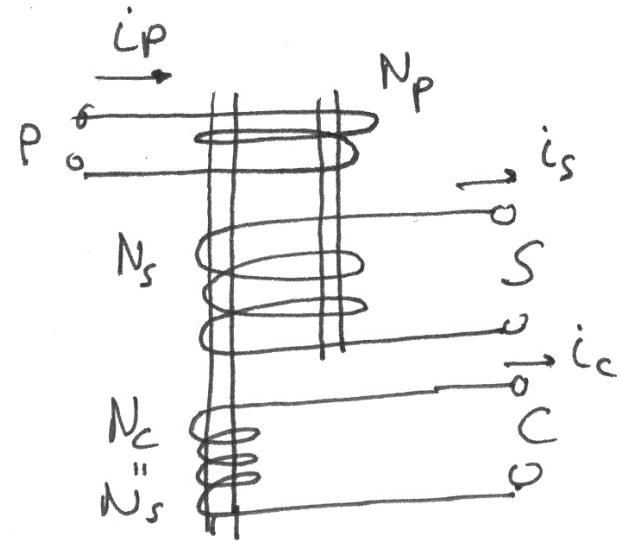
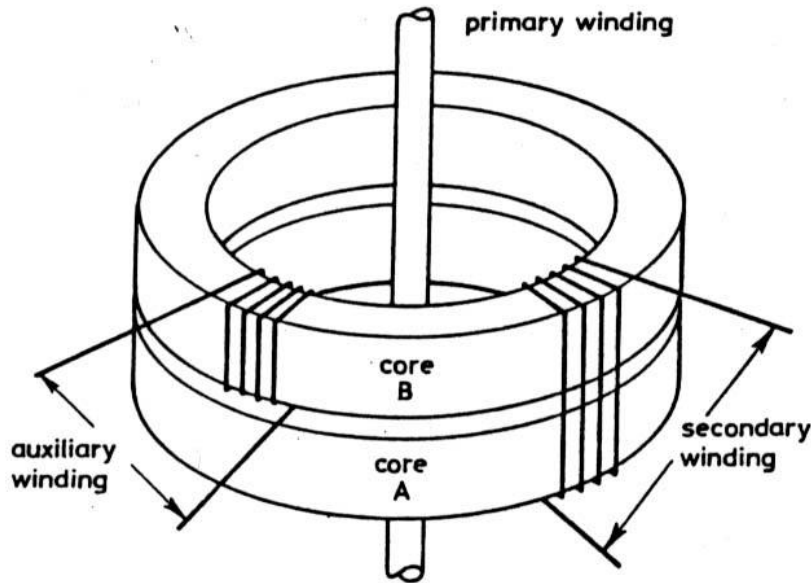
- Rangos de corriente
- Clase de precisión
- Potencia de precisión



- Relación de transformación: 5 . . . 1200 / 5 A
- Exactitud: $\pm 0,005 \% \pm 0,5'$ para corriente comprendida entre el 1 % y el 120 % de I_n
- Carga sobre el bobinado principal: 5 VA (Bornes S)

Two-stage standard transformer

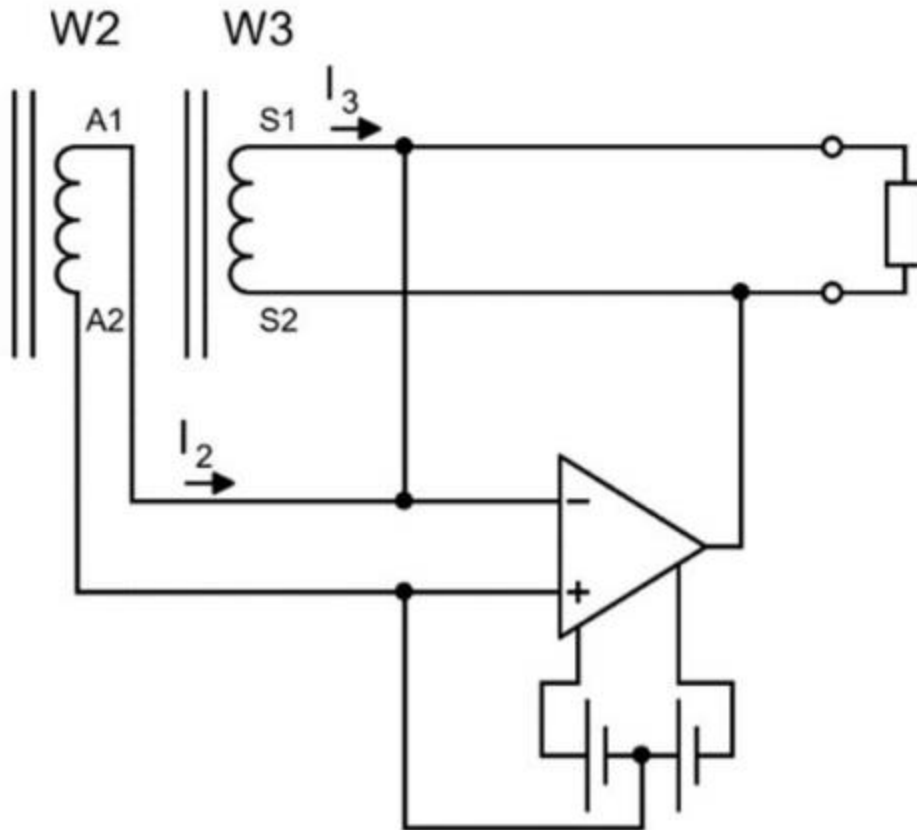
(Betts, 1983)



$$N_S i_C = N_P i_P - N_S i_S$$

- Errors lower than $10 \mu\text{A/A}$ and $10 \mu\text{rad}$ can be achieved.
- Using only one stage, errors increase up to $350 \mu\text{A/A}$ and $500 \mu\text{rad}$.

Transformador doble etapa



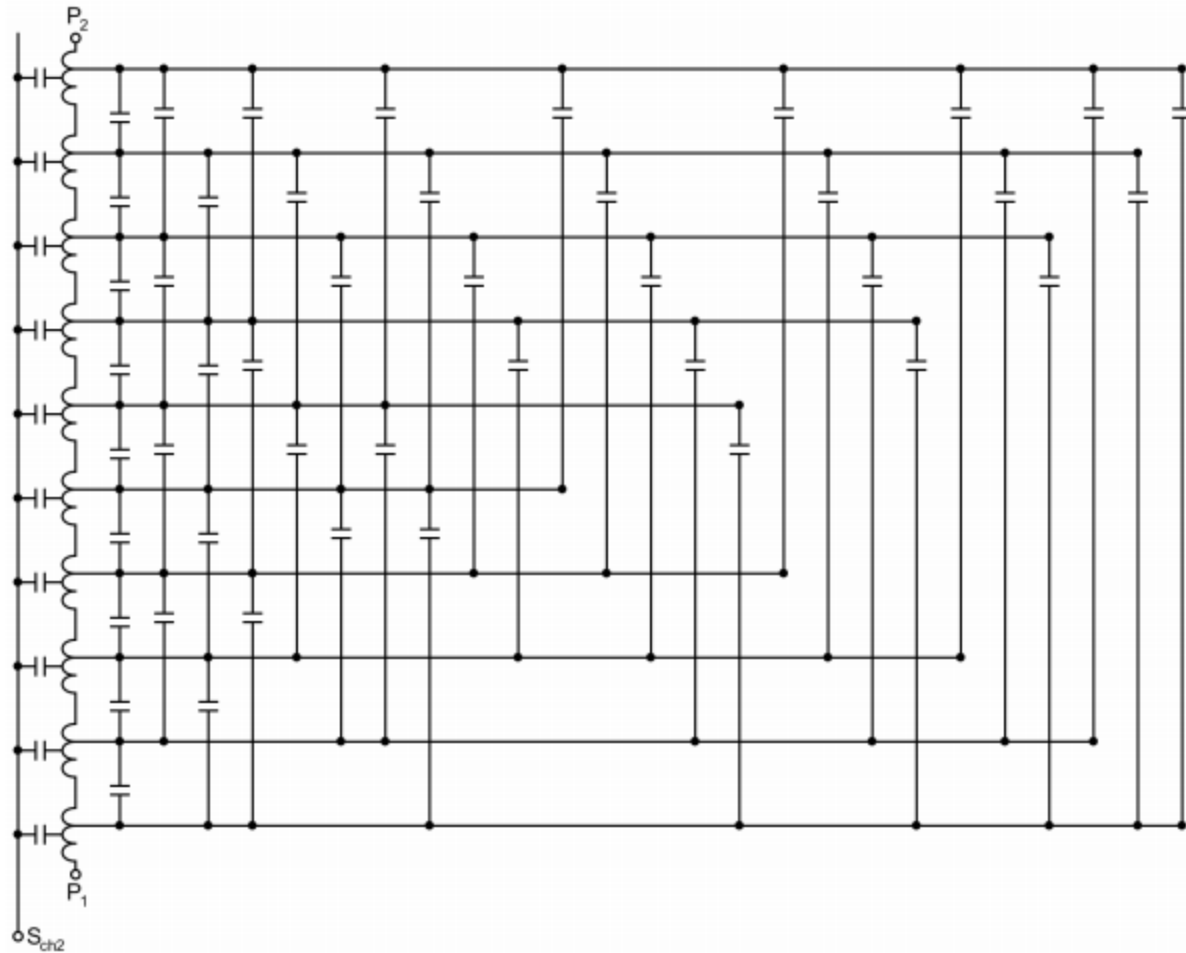
Sumador electrónico de corriente de compensación.

I_3 : corriente secundaria

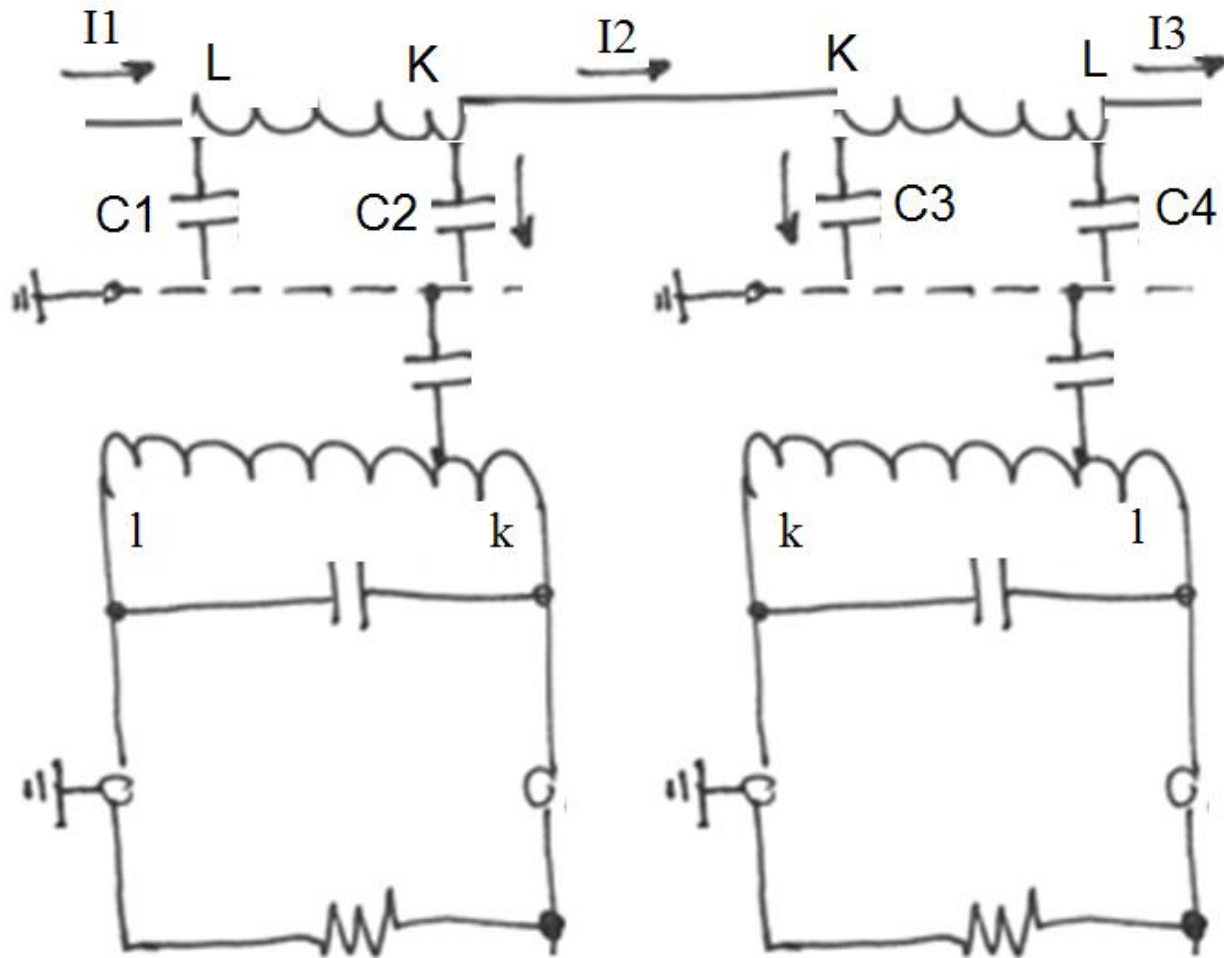
I_2 : corriente de compensación.

D. Slomovitz, A. Santos, R. Sandler and G. Barreto, "High-Precision Self-Calibrating Current Transformer With Stray Capacitances Control," in *IEEE Transactions on Instrumentation and Measurement*, vol. 70, pp. 1-9, 2021

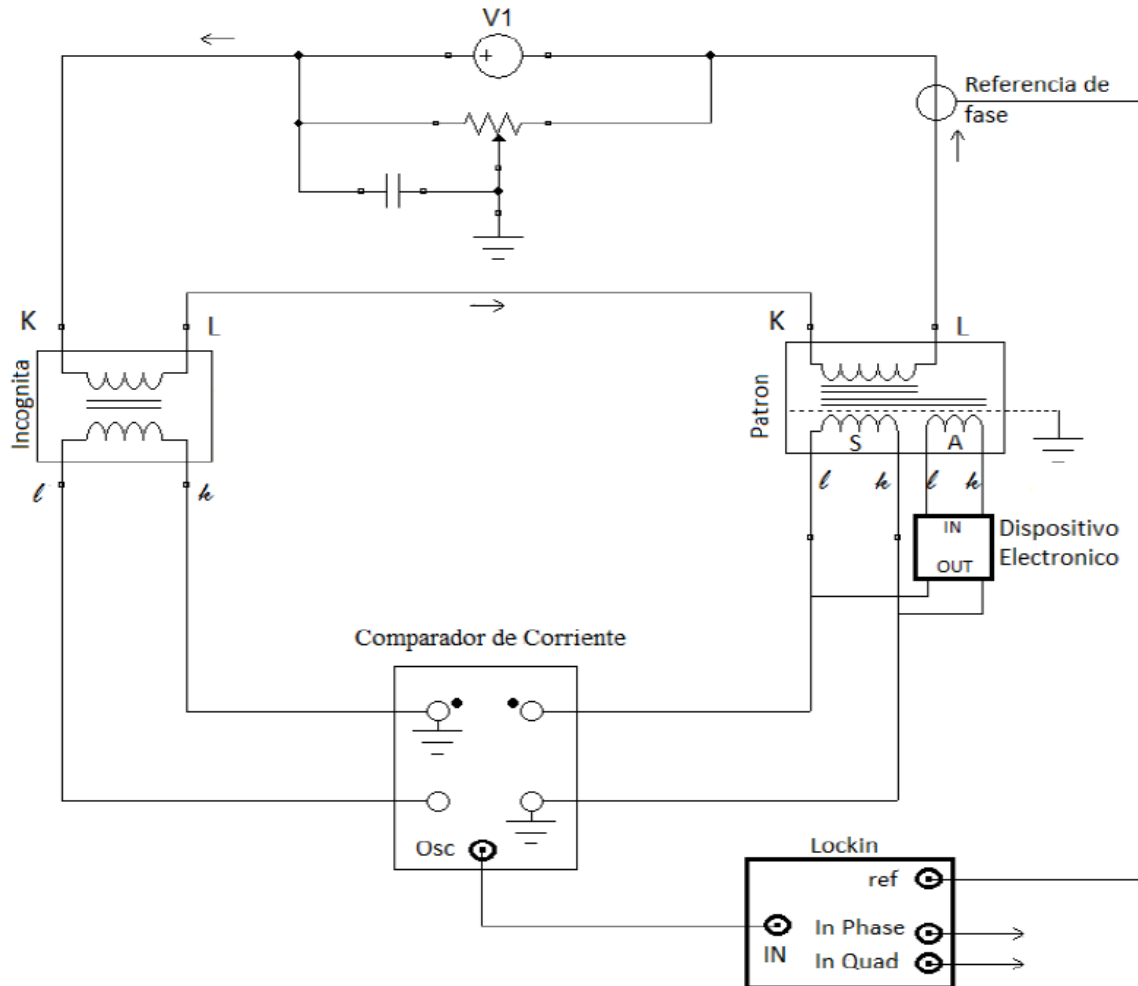
Capacidades parásitas



Capacidades parásitas



Tierra de Wagner



Fin