UNIVERSIDAD DE BUENOS AIRES
FACULTAD DE INGENIERÍA
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CIRCUITOS ELECTRÓNICOS I (66.08)

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Índice

1. Transistor Bipolar de Juntura

Modo activo directo:
NPN:
$V_{CE_Q} > V_{BE_Q} = 0{,}7V$
PNP:
$V_{CE_Q} < V_{BE_Q} = -0{,}7V$
$\Downarrow$
$I_B = \frac{I_C}{\beta} = \frac{I_E}{\beta+1}$

Saturación:
NPN:
$V_{CE_Q} < V_{BE_Q} = 0{,}7V$
PNP:
$V_{CE_Q} > V_{BE_Q} = -0{,}7V$
$\Downarrow$
$I_C \sim \frac{V_{CC} - V_{EE}}{R_C + R_E}$

Corte:
NPN:
$V_{BE_Q} = 0{,}7V$
PNP:
$V_{BE_Q} = -0{,}7V$
$\Downarrow$
$I_C = I_B = I_E = 0$

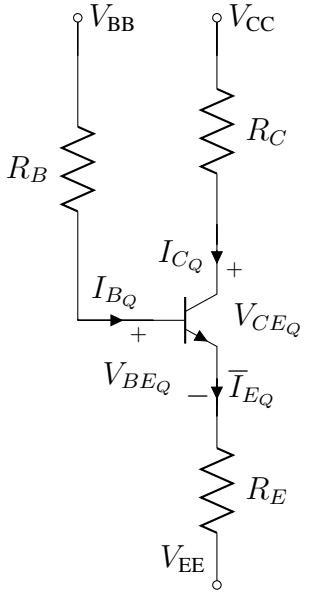

Figura 1.1: Circuito en continua

Malla de entrada:
$V_{BB} - I_{B_Q}R_B - V_{BE_Q} - I_{E_Q}R_E - V_{EE} = 0$
$I_{B_Q} = \frac{V_{BB} - V_{BE_Q} - V_{EE}}{R_B + (\beta+1)R_E} = \frac{I_{C_Q}}{\beta}$
Malla de salida:
$V_{CC} - I_{C_Q}R_C - V_{CE_Q} - I_{E_Q}R_E - V_{EE} = 0$
$I_{C_Q} = \frac{V_{CC} - V_{CE_Q} - V_{EE}}{R_C + R_E}$
Recta de carga estática:
$I_{C_Q} = \frac{V_{CC} - V_{EE}}{R_C + R_E} - \frac{V_{CE_Q}}{R_C + R_E}$
Recta de carga dinámica:
$i_C(t) = I_{C_Q} + \frac{V_{CE_Q}}{R_{C_L} + R_E} - \frac{v_{CE}(t)}{R_{C_L} + R_E}$

1.1. Modelo de pequeña señal

$$R_{ib} = \frac{v_b}{i_b} = \frac{i_b r_\pi + i_e R_E}{i_b} = \frac{i_b(r_\pi + (\beta+1)R_E)}{i_b} \sim r_\pi + \beta R_E = r_\pi(1 + g_m R_E)$$

$$R_{ic} = \frac{v_c}{i_c} = \frac{i_c r_o + i_c r_o \left(\beta \frac{R_E}{R_E + R_B + r_\pi}\right)}{i_c} = r_o \left(1 + \frac{\beta R_E}{R_E + R_B + r_\pi}\right)$$

$$R_{ie} = \frac{v_e}{i_e} = \frac{v_e}{\frac{v_e}{r_\pi + R_B \parallel R_s}(\beta+1)} = \frac{r_\pi + R_B \parallel R_s}{\beta+1}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta}{g_m} = \beta \frac{V_T}{I_C Q} = \frac{V_T}{I_{BQ}}$$

$$r_o = \frac{V_A}{I_{CQ}}$$

1.1.1. Emisor común

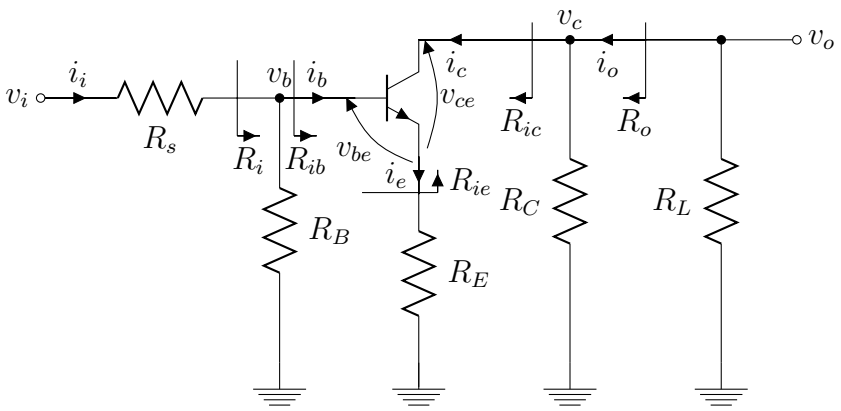

Figura 1.2: Circuito de alterna emisor común

$$R_i = R_B \parallel R_{ib} = R_B \parallel r_\pi(1 + g_m R_E)$$

$$R_o = R_C \parallel R_{ic} = R_C \parallel r_o \left(1 + \frac{\beta R_E}{R_E + R_B + r_\pi}\right)$$

$$A_v = \frac{v_c}{v_b} = \frac{-g_m v_{be} R_{C_L}}{v_b} = \frac{-g_m v_b \frac{r_\pi}{r_\pi + \beta R_E} R_{C_L}}{v_b} = -\frac{g_m r_\pi R_{C_L}}{r_\pi + \beta R_E} = \frac{-g_m r_\pi R_{C_L}}{r_\pi + g_m r_\pi R_E} = \frac{-g_m R_{C_L}}{1 + g_m R_E}$$

$$A_{vs} = \frac{v_o}{v_i} = \frac{v_c}{v_b}\frac{v_b}{v_i} = A_v \frac{R_i}{R_i + R_s}$$

1.1.2. Colector común

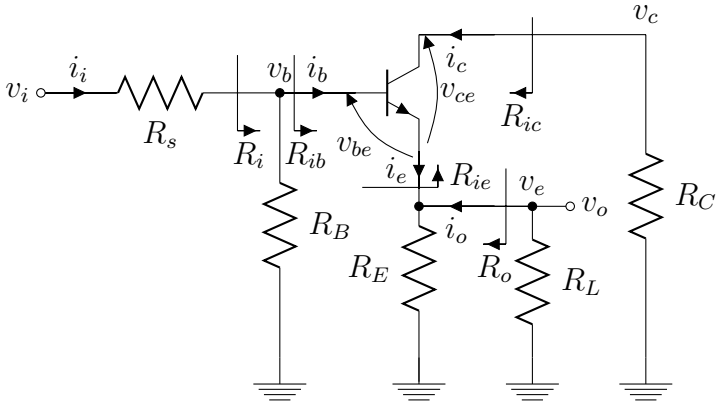

Figura 1.3: Circuito de alterna colector común

$$R_i = R_B \parallel R_{ib} = R_B \parallel r_\pi(1 + g_m R_E)$$

$$R_o = R_E \parallel R_{ie} = R_E \parallel \left(\frac{r_\pi + R_B \parallel R_s}{\beta + 1} \right)$$

$$A_v = \frac{v_e}{v_b} = \frac{g_m v_{be} R_{E_L}}{v_b} = \frac{g_m v_b \frac{r_\pi}{r_\pi + \beta R_{E_L}} R_{E_L}}{v_b} = \frac{g_m r_\pi R_{E_L}}{r_\pi + g_m r_\pi R_{E_L}} = \frac{g_m R_{E_L}}{1 + g_m R_{E_L}} \sim 1$$

$$A_{vs} = \frac{v_o}{v_i} = \frac{v_e}{v_b} \frac{v_b}{v_i} = A_v \frac{R_i}{R_i + R_s}$$

1.1.3. Base común

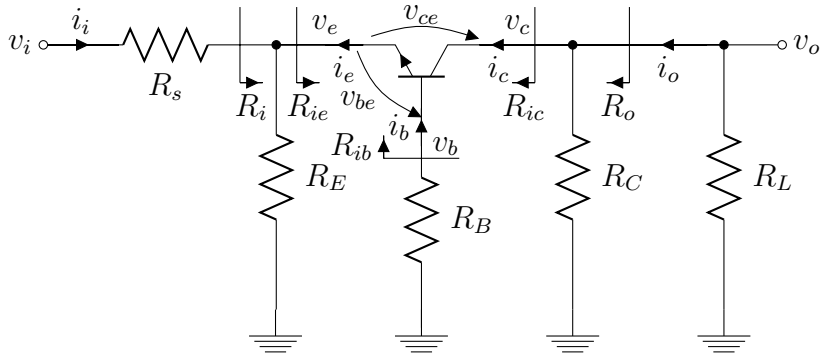

Figura 1.4: Circuito de alterna base común

$$R_i = R_E \parallel R_{ie} = R_E \parallel \frac{r_\pi + R_B \parallel R_s}{\beta + 1}$$

$$R_o = R_C \parallel R_{ic} = R_C \parallel r_o \left(1 + \frac{\beta R_E}{R_E + R_B + r_\pi} \right)$$

$$A_v = \frac{v_c}{v_e} = \frac{-g_m v_{be} R_{C_L}}{v_e} = \frac{-g_m v_e \left(\frac{-r_\pi}{r_\pi + R_B} \right) R_{C_L}}{v_e} = \frac{g_m r_\pi R_{C_L}}{r_\pi + R_B} = \frac{\beta R_{C_L}}{r_\pi + R_B}$$

$$A_{vs} = \frac{v_o}{v_i} = \frac{v_c}{v_e} \frac{v_e}{v_i} = A_v \frac{R_i}{R_i + R_s}$$

2. MOSFET y JFET

MOSFET:

Modo óhmico:	Saturación:	Corte:
Canal N:	Canal N:	Canal N:
$V_{GS} > V_T >$ y $V_{DS} < V_{GS} - V_T$	$V_{GS} > V_T$ y $V_{DS} > V_{GS} - V_T$	$V_{GS} < V_T$
Canal P:	Canal P:	Canal P:
$V_{GS} < V_T >$ y $V_{DS} > V_{GS} - V_T$	$V_{GS} < V_T$ y $V_{DS} < V_{GS} - V_T$	$V_{GS} > V_T$
$\Downarrow$	$\Downarrow$	$\Downarrow$
$I_D = k \left(V_{GS} - V_T - \frac{V_{DS}}{2} \right) V_{DS}$	$I_D = \frac{k}{2} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$	$I_D = I_S = I_G = 0$

JFET:

Modo triodo:
Canal N:
$V_{GS} > V_p$ y $0 < V_{DS} < V_{GS} - V_p$
Canal P:
$V_{GS} < V_p$ y $0 > V_{DS} > V_{GS} - V_p$
$\Downarrow$
$$I_D = 2\frac{I_{DSS}}{V_p^2}\left(V_{GS} - V_p - \frac{V_{DS}}{2}\right)V_{DS}$$

Estrangulamiento:
Canal N:
$V_{GS} < V_p$ y $V_{DS} < V_{GS} - V_p < 0$
Canal P:
$V_{GS} > V_p$ y $V_{DS} > V_{GS} - V_p > 0$
$\Downarrow$
$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2 (1 + \lambda V_{DS})$$

Corte:
Canal N:
$V_{GS} > V_p$
Canal P:
$V_{GS} < V_p$
$\Downarrow$
$$I_D = I_S = I_G = 0$$

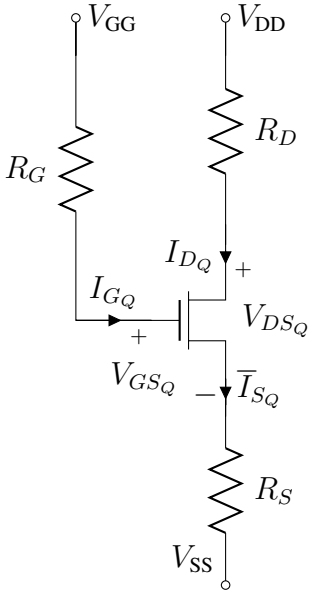

Figura 2.1: Circuito en continua

Malla de entrada:
$$V_{GG} - I_{G_Q}R_G - V_{GS_Q} - I_{S_Q}R_S - V_{SS} = 0$$
$$I_{GQ} = 0$$
$$I_{D_Q} = I_{S_Q} = \frac{V_{GG} - V_{GS_Q} - V_{SS}}{R_S}$$
Malla de salida:
$$V_{DD} - I_{D_Q}R_D - V_{DS_Q} - I_{S_Q}R_S - V_{SS} = 0$$
$$I_{D_Q} = I_{S_Q} = \frac{V_{DD} - V_{DS_Q} - V_{SS}}{R_D + R_S}$$
Recta de carga estática:
$$I_{D_Q} = \frac{V_{DD} - V_{SS}}{R_D + R_S} - \frac{V_{DS_Q}}{R_D + R_S}$$
Recta de carga dinámica:
$$i_D(t) = I_{D_Q} + \frac{V_{DS_Q}}{R_{D_L} + R_S} - \frac{v_{DS}(t)}{R_{D_L} + R_S}$$

2.1. Modelo de pequeña señal

$$R_{ig} = \frac{v_g}{i_g} = \frac{i_g r_{gs} + i_s R_S}{i_g} = \frac{i_g(r_{gs} + (\beta+1)R_S)}{i_g} \sim r_{gs} + \beta R_S = r_{gs}(1 + g_m R_S) \to \infty$$

$$R_{id} = \frac{v_d}{i_d} = \frac{i_d r_{ds} + i_d r_{ds}\left(\beta \frac{R_S}{R_S + R_G + r_{gs}}\right)}{i_d} = r_{ds}\left(1 + \frac{g_m r_{gs} R_S}{R_S + R_G + r_{gs}}\right) = r_{ds}\left(1 + g_m R_S\right)$$

$$R_{is} = \frac{v_s}{i_s} = \frac{v_s}{\frac{v_s}{r_{gs} + R_G \parallel R_s}(g_m r_{gs} + 1)} = \frac{r_{gs} + R_G \parallel R_s}{g_m r_{gs} + 1} \sim \frac{1}{g_m}$$

$$g_m = 2\sqrt{k I_{DQ}}$$

$$r_{ds} = \frac{1}{\lambda I_{DQ}}$$

2.1.1. Source común

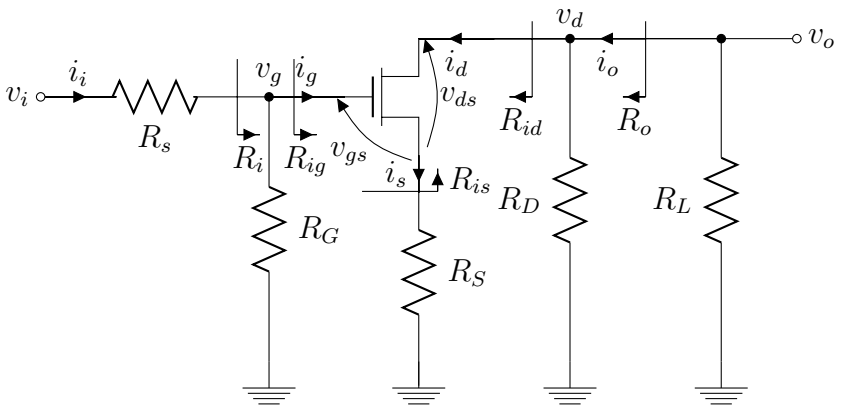

Figura 2.2: Circuito de alterna emisor común

$$R_i = R_G \parallel R_{ig} = R_G$$

$$R_o = R_D \parallel R_{id} = R_D \parallel r_{ds}\,(1 + g_m R_S) = R_D$$

$$A_v = \frac{v_d}{v_g} = \frac{-g_m v_{gs} R_D}{v_g} = \frac{-g_m v_g \frac{r_{gs}}{r_{gs}+g_m r_{gs} R_S} R_D}{v_g} = -\frac{g_m r_{gs} R_D}{r_{gs} + g_m r_{gs} R_E} = \frac{-g_m R_D}{1 + g_m R_S}$$

$$A_{vs} = \frac{v_o}{v_i} = \frac{v_d}{v_g}\frac{v_g}{v_i} = A_v \frac{R_i}{R_i + R_s}$$

2.1.2. Drain común

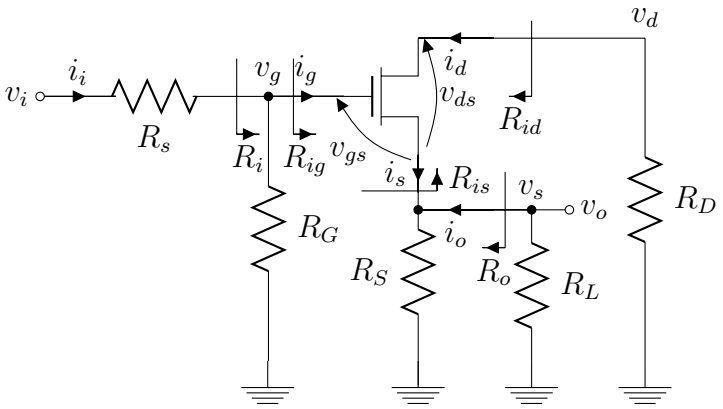

Figura 2.3: Circuito de alterna drain común

$$R_i = R_G \parallel R_{ig} = R_G \parallel r_{gs}(1 + g_m R_S) \sim R_G$$

$$R_o = R_S \parallel R_{is} = R_S \parallel \left(\frac{r_{gs} + R_G \parallel R_s}{g_m r_{gs} + 1}\right) \sim R_S \parallel \left(\frac{1}{g_m}\right)$$

$$A_v = \frac{v_s}{v_g} = \frac{g_m v_{gs} R_{S_L}}{v_g} = \frac{g_m v_g \frac{r_{gs}}{r_{gs}+g_m r_{gs} R_{S_L}} R_{S_L}}{v_g} = \frac{g_m r_{gs} R_{S_L}}{r_{gs} + g_m r_{gs} R_{S_L}} = \frac{g_m R_{S_L}}{1 + g_m R_{S_L}} \sim 1$$

$$A_{vs} = \frac{v_o}{v_i} = \frac{v_s}{v_g}\frac{v_g}{v_i} = A_v \frac{R_i}{R_i + R_s}$$

2.1.3. Gate común

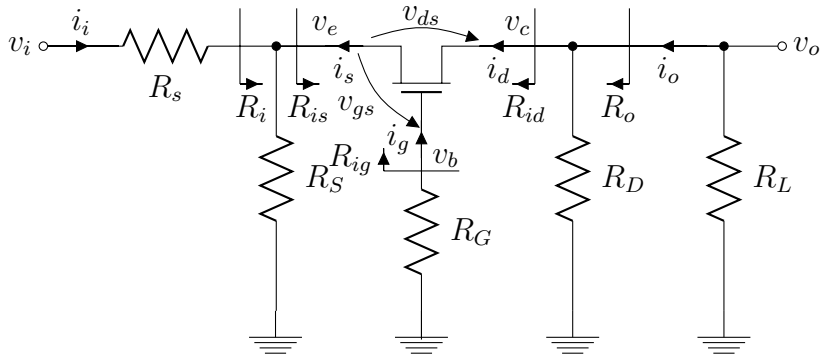

Figura 2.4: Circuito de alterna gate común

$$R_i = R_S \parallel R_{is} = R_S \parallel \left(\frac{r_{gs} + R_G \parallel R_s}{g_m r_{gs} + 1}\right) \sim R_S \parallel \left(\frac{1}{g_m}\right)$$

$$R_o = R_D \parallel R_{id} = R_D \parallel r_{ds}\left(1 + \frac{g_m r_{gs} R_S}{R_S + R_G + r_{gs}}\right) \sim R_D \parallel r_{ds}\left(1 + g_m R_S\right)$$

$$A_v = \frac{v_d}{v_s} = \frac{-g_m v_{gs} R_{D_L}}{v_s} = \frac{-g_m v_s \left(\frac{-r_{gs}}{r_{gs}+R_G}\right) R_{D_L}}{v_s} = \frac{g_m r_{gs} R_{D_L}}{r_{gs} + R_G} \sim g_m R_{D_L}$$

$$A_{vs} = \frac{v_o}{v_i} = \frac{v_d}{v_s}\frac{v_s}{v_i} = A_v \frac{R_i}{R_i + R_s}$$

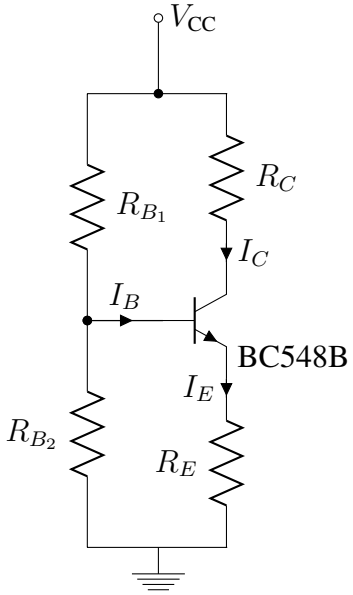

Figura 2.5: Circuito en Continua

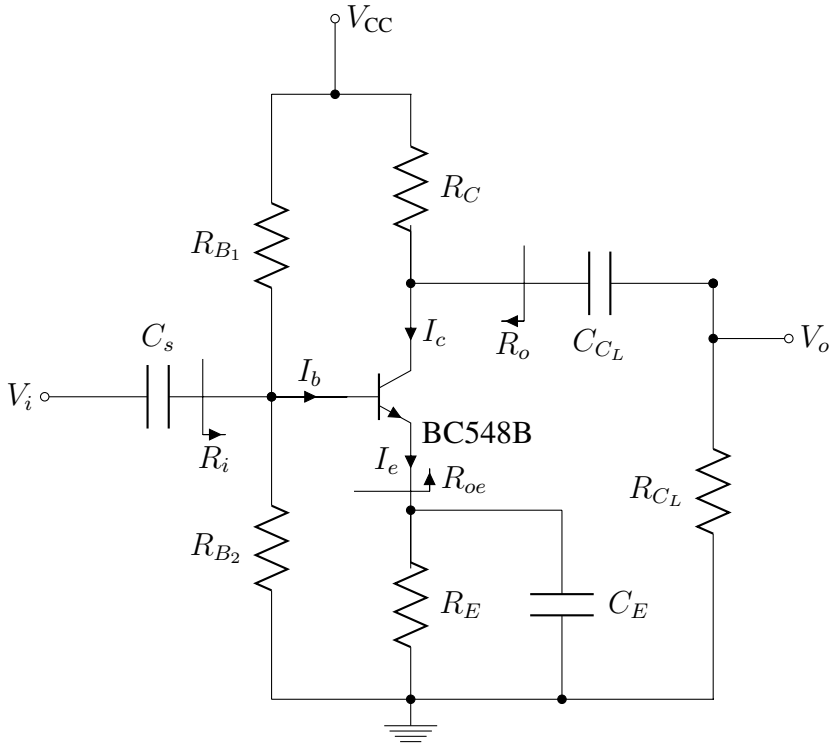

Figura 2.6: Circuito propuesto

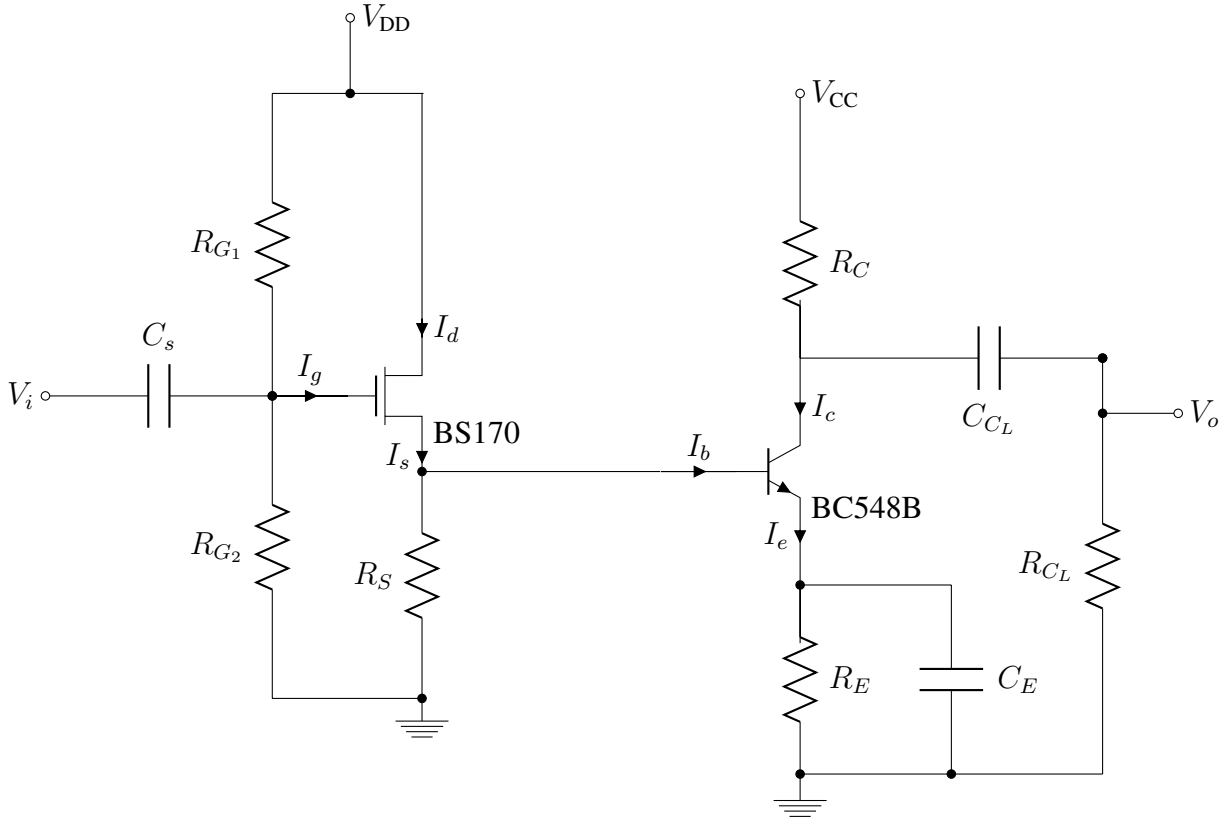

Figura 2.7: Circuito dos etapas

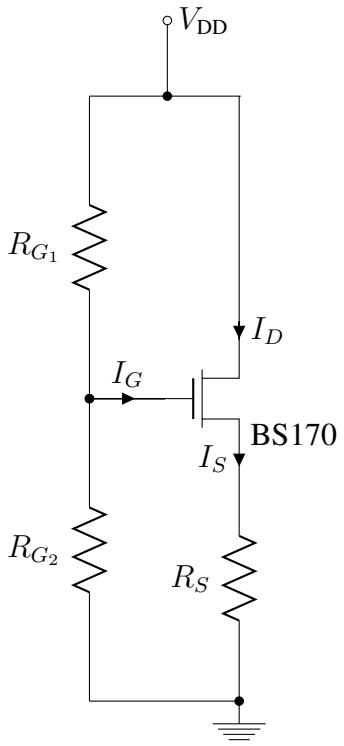

Figura 2.8: Circuito en Continua

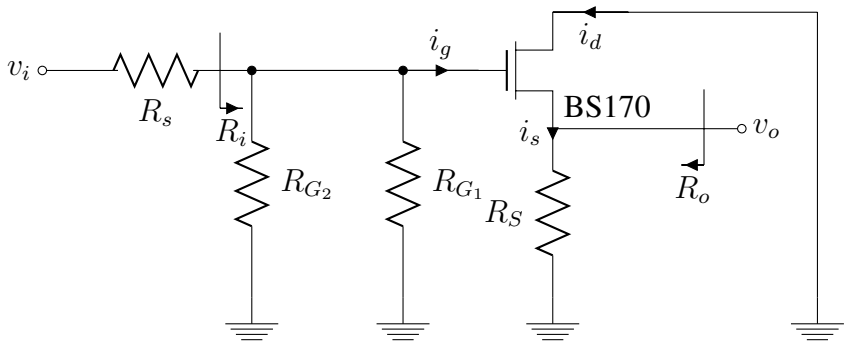

Figura 2.9: Circuito en señal

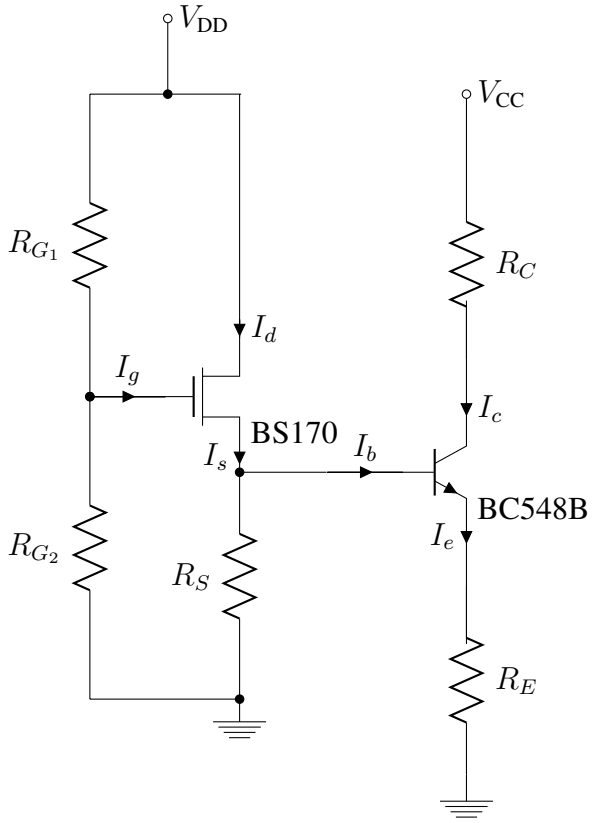

Figura 2.10: Circuito en Continua

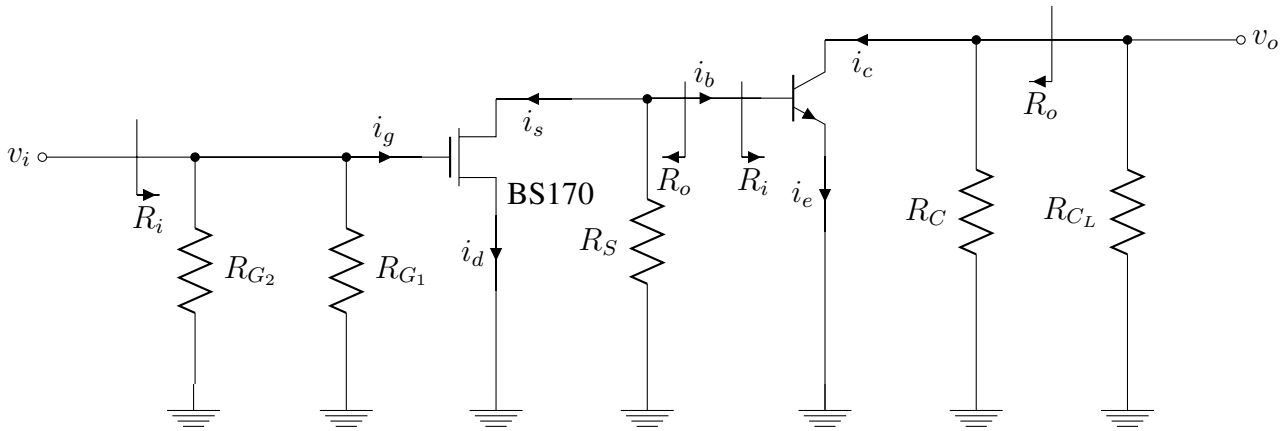

Figura 2.11: Circuito en señal

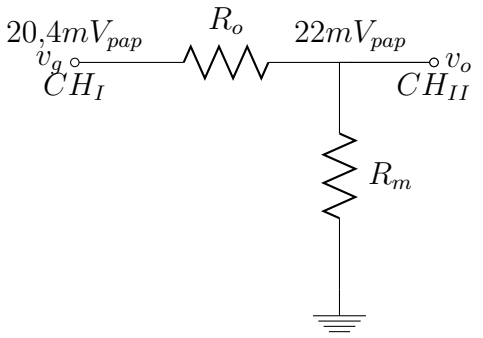

Figura 2.12: Banco de medición equivalente

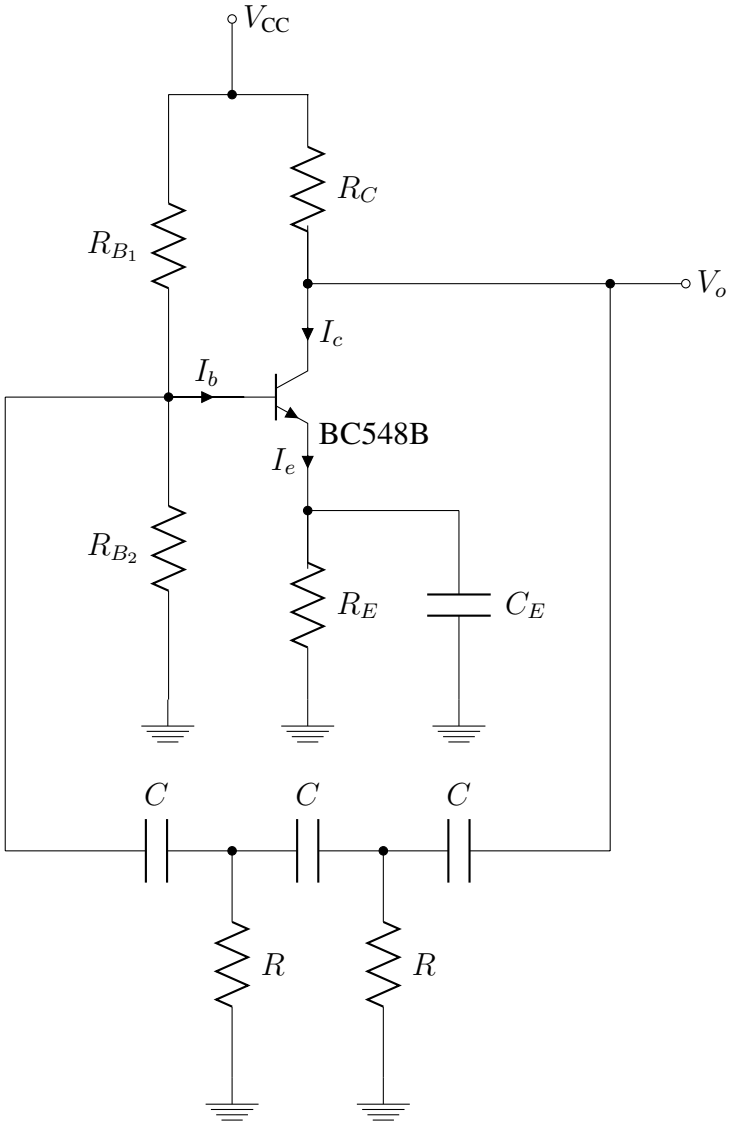

Figura 2.13: Oscilador de corrimiento de fase