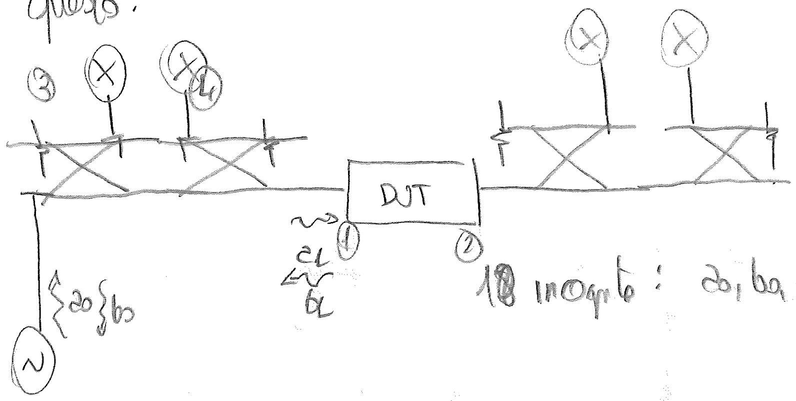
T1

Il modello è questo:



18 incognite: $a_0, b_0, a_1, b_1, a_2, b_2, a_3, b_3, a_4, b_4$

A 1 porta: $a_0, b_0, a_1, b_1, a_3, b_3, a_4, b_4$

Si ha:

$$\begin{bmatrix} b_0 \\ b_1 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_3 \\ a_4 \end{bmatrix}$$

ma ho queste relazioni:

$a_3 = \Gamma_3 b_3$; $a_4 = \Gamma_4 b_4$;

$a_{m1} = K_3 b_3$; $a_{m2} = K_4 b_4$

voglio ciò: $\begin{bmatrix} c_1 & c_2 \\ c_3 & c_4 \end{bmatrix}$!

$$\begin{cases} a_{m1} = c_1 V_{m1} + c_2 V_{m2} \\ b_{m1} = c_3 V_{m1} + c_4 V_{m2} \end{cases}$$

$$\begin{cases} b_0 = S_{11} a_0 + S_{12} a_1 + S_{13} a_3 + S_{14} a_4 \\ b_1 = S_{21} a_0 + S_{22} a_1 + S_{23} a_3 + S_{24} a_4 \\ b_3 = S_{31} a_0 + S_{32} a_1 + S_{33} a_3 + S_{34} a_4 \\ b_4 = S_{41} a_0 + S_{42} a_1 + S_{43} a_3 + S_{44} a_4 \end{cases} \longrightarrow \begin{cases} -S_{11} a_0 + b_0 - S_{12} a_1 = S_{13} a_3 + S_{14} a_4 \\ -S_{21} a_0 - S_{22} a_1 + b_1 = S_{23} a_3 + S_{24} a_4 \\ -S_{31} a_0 - S_{32} a_1 = S_{33} a_3 - b_3 + S_{34} a_4 \\ -S_{41} a_0 - S_{42} a_1 = S_{43} a_3 + S_{44} a_4 - b_4 \end{cases}$$

$$\begin{bmatrix} -S_{11} & 1 & -S_{12} & 0 \\ -S_{21} & 0 & -S_{22} & 1 \\ -S_{31} & 0 & -S_{32} & 0 \\ -S_{41} & 0 & -S_{42} & 0 \end{bmatrix} \begin{bmatrix} a_0 \\ b_0 \\ a_1 \\ b_1 \end{bmatrix} = \begin{bmatrix} S_{13}\Gamma_3 & S_{14}\Gamma_4 \\ S_{23}\Gamma_3 & S_{24}\Gamma_4 \\ S_{33}\Gamma_3 - 1 & S_{34}\Gamma_4 \\ S_{43}\Gamma_3 & S_{44}\Gamma_4 - 1 \end{bmatrix} \begin{bmatrix} b_3 \\ b_4 \end{bmatrix}$$

$$\underline{\underline{W}} \begin{bmatrix} a_0 \\ b_0 \\ a_1 \\ b_1 \end{bmatrix} = \underline{\underline{Q}} \begin{bmatrix} b_3 \\ b_4 \end{bmatrix}$$

ma poi:

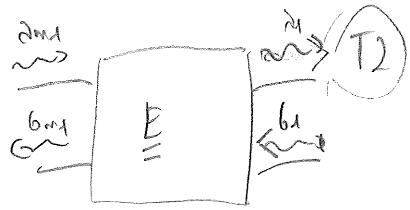
$$\begin{bmatrix} a_{m1} \\ b_{m1} \end{bmatrix} = \begin{bmatrix} K_3 & 0 \\ 0 & K_4 \end{bmatrix} \begin{bmatrix} b_3 \\ b_4 \end{bmatrix} = \underline{\underline{K}} \begin{bmatrix} b_3 \\ b_4 \end{bmatrix} \longrightarrow \begin{bmatrix} b_3 \\ b_4 \end{bmatrix} = \underline{\underline{K}}^{-1} \begin{bmatrix} a_{m1} \\ b_{m1} \end{bmatrix}$$

$$\begin{bmatrix} a_0 \\ b_0 \\ a_1 \\ b_1 \end{bmatrix} = \underline{\underline{W}}^{-1} \underline{\underline{Q}} \begin{bmatrix} b_3 \\ b_4 \end{bmatrix} = \boxed{\underbrace{\underline{\underline{W}}^{-1} \underline{\underline{Q}}^{-1} \underline{\underline{K}}^{-1}}_{\underline{\underline{D}}} \begin{bmatrix} a_{m1} \\ b_{m1} \end{bmatrix}} \Rightarrow$$

$$\begin{cases} a_0 = D_{11} a_{m1} + D_{12} b_{m1} \\ b_0 = D_{21} a_{m1} + D_{22} b_{m1} \\ a_1 = D_{31} a_{m1} + D_{32} b_{m1} \\ b_1 = D_{41} a_{m1} + D_{42} b_{m1} \end{cases}$$

ovvero ciò!

$$\begin{cases} a_1 = D_{31}\, a_{m1} + D_{32}\, b_{m1} \\ b_1 = D_{41}\, a_{m1} + D_{42}\, b_{m1} \end{cases} \longrightarrow \begin{cases} b_{m1} = e_{11}\, a_{m1} + e_{12}\, b_1 \\ a_1 = e_{21}\, a_{m1} + e_{22}\, b_1 \end{cases}$$



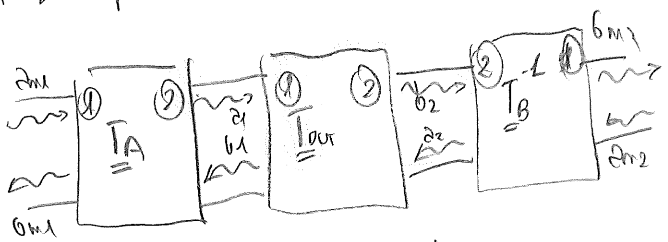
sostituisco: $a_{m1} \Rightarrow a_1$; $b_{m1} \Rightarrow b_1$; $a_1 \Rightarrow b_2$; $b_1 \Rightarrow a_2$

$$\hookrightarrow \begin{cases} b_1 = S_{11}\, a_1 + S_{12}\, a_2 \\ b_2 = S_{21}\, a_1 + S_{22}\, a_2 \end{cases} \xrightarrow{\text{desostituisco}} \begin{cases} b_{m1} = e_{11}\, a_{m1} + e_{12}\, b_1 \\ a_1 = e_{21}\, a_{m1} + e_{22}\, b_1 \end{cases} = \ldots$$

$$\hookrightarrow \boxed{\Gamma_m = e_{11} + \frac{e_{12}\, e_{21}\, \Gamma_x}{1 - e_{22}\, \Gamma_1}}$$

e_{11}: directivity error $e_{12} e_{21}$: tracking error
e_{22}: source match error;

A 2 porte:



dove: misuro:

$$\begin{bmatrix} b_{m1} \\ b_{m2} \end{bmatrix} = \begin{bmatrix} S_{m11} & S_{m12} \\ S_{m21} & S_{m22} \end{bmatrix} \begin{bmatrix} a_{m1} \\ a_{m2} \end{bmatrix}$$

Questa è la configurazione!

$\underline{\underline{T}}_m = \underline{\underline{T}}_A\, \underline{\underline{T}}_{DUT}\, \underline{\underline{T}}_B^{-1}$ $\underline{\underline{T}}_{DUT}$ è quella di uno standard prima della calibrazione o di un DUT (un transistor x esempio) dopo

Definisco:

$$\underline{\underline{S}}_{thru} = \begin{bmatrix} 0 & \exp(-jkl_T) \\ \exp(-jkl_T) & 0 \end{bmatrix}; \quad \underline{\underline{T}} = \frac{1}{S_{21}} \begin{bmatrix} \Delta & S_{11} \\ -S_{22} & 1 \end{bmatrix} \quad \Delta = S_{11} S_{22} - S_{21} S_{12}$$

$$\underline{\underline{T}}_{thru} = \exp(jkl_T) \begin{bmatrix} -\exp(-j2kl_T) & 0 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} -\exp(-jkl_T) & 0 \\ 0 & \exp(jkl_T) \end{bmatrix}$$

$$\underline{\underline{T}}_{thru}^{-1} = \begin{bmatrix} d & -b \\ -c & a \end{bmatrix} \frac{1}{det} = \begin{bmatrix} -\exp(jkl_T) & 0 \\ 0 & \exp(-jkl_T) \end{bmatrix} \quad \underline{\underline{T}}_{line}\, \underline{\underline{T}}_{thru}^{-1} = \begin{bmatrix} \exp(-jk(l_L - l_T)) & 0 \\ 0 & \exp(jk(l_L - l_T)) \end{bmatrix}$$

$$\begin{bmatrix} -\exp(-jkl_L) & 0 \\ 0 & \exp(jkl_L) \end{bmatrix} \begin{bmatrix} -\exp(jkl_T) & 0 \\ 0 & \exp(-jkl_T) \end{bmatrix}$$

Si definisce $\underline{\underline{R}}_m$ come:

$$\underline{\underline{R}}_m = \underline{\underline{T}}_{thru,m}\, \underline{\underline{T}}_{thru,m}^{-1} = \underline{\underline{T}}_A \underline{\underline{T}}_{thr} \underline{\underline{T}}_B^{-1} \left(\underline{\underline{T}}_A \underline{\underline{T}}_{thru} \underline{\underline{T}}_B^{-1} \right)^{-1} = \underline{\underline{T}}_A \underline{\underline{T}}_{thr} \underline{\underline{T}}_{thr}^{-1} \underline{\underline{T}}_A^{-1}$$

$\underline{\underline{T}}_A$ diagonalizza $\underline{\underline{R}}_m$!

$\hookrightarrow$ $\underline{\underline{T}}_A$ ha forma: $[\underline{v}_1, \underline{v}_2]$, dove $\underline{v}_1 = \begin{bmatrix} Ka \\ K \end{bmatrix}$ $\underline{v}_2 = \begin{bmatrix} p\,b \\ p \end{bmatrix}$

$\hookrightarrow$ $\underline{\underline{T}}_A = p \begin{bmatrix} \frac{K}{p} a & b \\ \frac{K}{p} & 1 \end{bmatrix}$;

$$\Gamma_{m1} = e_{11} + \frac{e_{21} e_{12} \Gamma_x}{1 - e_{22}\Gamma_x} = \frac{e_{11} - e_{11} e_{22} \Gamma_x + e_{21} e_{12} \Gamma_x}{1 - e_{22}\Gamma_x} = \frac{\frac{e_{11}}{e_{21}} - \frac{e_{11} e_{22} - e_{21} e_{12}}{e_{21}} \Gamma_x}{\frac{1}{e_{21}} - \frac{e_{22}}{e_{21}} \Gamma_x} =$$

$$= \frac{b + \frac{K}{p} a \Gamma_x}{1 + \frac{K}{p} \Gamma_x}$$

dovrei (e lo faccio tra breve) farlo con la parte 2.

TSD: Thru-Short-Delay. Che misure si fanno?

Short:

$$\Gamma_{mS} = \frac{b + \frac{K}{p} a \Gamma_S}{1 + \frac{K}{p} \Gamma_S}$$

; a e b noti, Γ_S e Γ_{mS} noti, $\frac{K}{p}$ incognito: posso determinarlo da qui.

Posso poi dire:

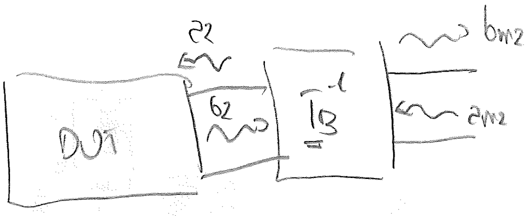
Thru:

$$\underline{\underline{T}}_{Thru\,m} = \underline{\underline{T}}_A \underline{\underline{T}}_{thru} \underline{\underline{T}}_B^{-1} = p\, \underbrace{\underline{\underline{X}}_A}_{\text{nota}} \underline{\underline{T}}_{thru} \underline{\underline{T}}_B^{-1} = \underline{\underline{X}}_A \underline{\underline{T}}_{thru} \underbrace{\left\{ \frac{1}{p} \underline{\underline{T}}_B \right\}^{-1}}_{\tilde{\underline{\underline{T}}}_B^{-1}}$$

$\hookrightarrow$ $\boxed{\tilde{\underline{\underline{T}}}_B = \underline{\underline{T}}_{m\,thru}^{-1} \underline{\underline{X}}_A \underline{\underline{T}}_{thru}}$ $\rightsquigarrow$ $\boxed{\underline{\underline{T}}_{mDUT} = \underline{\underline{X}}_A \underline{\underline{T}}_{DUT} \tilde{\underline{\underline{T}}}_B^{-1}}$

TRL

Prima qualche ragionamento su $\underline{\underline{T_B}}$: ho, dal modello:



È evidente che la porta 1 è (per $\underline{\underline{T_B}}^{-1}$) quella a dx.

In questo caso,

$$\Gamma_{m2} = e_{11} + \frac{e_{21} e_{12} \Gamma_x}{1 - e_{22} \Gamma_x} \quad \text{(come prima!)}$$

Ora, dal momento che ho, in sequenza da dx a sx, prima il thru e poi la line,

$$R_{m2} = \underline{\underline{T}}_{m\,thru}^{-1} \underline{\underline{T}}_{m\,line} = \left(\underline{\underline{T_A}}\,\underline{\underline{T_t}}\,\underline{\underline{T_B}}^{-1}\right) \underline{\underline{T_A}}\,\underline{\underline{T_l}}\,\underline{\underline{T_B}}^{-1} = \underline{\underline{T_B}}\,\underline{\underline{T_t}}^{-1}\,\underline{\underline{T_l}}\,\underline{\underline{T_B}}^{-1}$$

Ora è $\underline{\underline{T_B}}$ a diagonalizzare $\underline{\underline{\Lambda}}$.

$$\underline{\underline{T_B}} = [u_1, u_2] = \begin{bmatrix} u g & w f \\ u & w \end{bmatrix} \quad g, f \text{ da prodotto autovettori.}$$

$$\hookrightarrow \underline{\underline{T_B}} \text{ ha forma } w \begin{bmatrix} \frac{u}{w} g & f \\ \frac{u}{w} & 1 \end{bmatrix} \iff \frac{1}{S_{21}} \begin{bmatrix} \Delta & S_{11} \\ -S_{22} & 1 \end{bmatrix}$$

così che:

$$\hookrightarrow \boxed{\Gamma_{m2} = \frac{f + \frac{u}{w} g \Gamma_x}{1 + \frac{u}{w} \Gamma_x}}$$

TRL: Thru, Reflect, Line (invece dello short ho un reflect!)

Abbiamo: $\frac{k}{p}$, $\frac{u}{w}$, manca $\frac{p}{w}$! $\alpha \triangleq \frac{p}{w}$! Vediamo: ricordo che:

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \longrightarrow \frac{1}{S_{21}} \begin{bmatrix} S_{11}S_{22} - S_{21}S_{12} & S_{11} \\ -S_{22} & 1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix}$$

$$T_{12} = \frac{S_{11}}{S_{21}}; \quad T_{22} = \frac{1}{S_{21}} \longrightarrow S_{11} = \frac{\frac{S_{11}}{S_{12}}}{\frac{1}{S_{12}}} = \frac{T_{12}}{T_{22}}$$

Considero punti fermo il thru:

$\hookrightarrow \underline{\underline{T_m}} = \underline{\underline{T_A}}\, \underline{\underline{T_B}}^{-1}$ $\qquad \underline{\underline{T_A}} = \begin{bmatrix} Ka & pb \\ K & p \end{bmatrix} \qquad \underline{\underline{T_B}} = \begin{bmatrix} ug & wf \\ u & w \end{bmatrix}$

$$\underline{\underline{T_B}}^{-1} = \frac{1}{ugw - uwf} \begin{bmatrix} w & -wf \\ -u & ug \end{bmatrix} \quad ; \quad \underline{\underline{T_m}} = \begin{bmatrix} Ka & pb \\ k & p \end{bmatrix} \begin{bmatrix} w & -wf \\ -u & ug \end{bmatrix} \frac{1}{ugw - uwf}$$

$$S_{mu} = \frac{T_{m12}}{T_{m22}} = \frac{1}{ugw - uwf} \frac{-Kawf + pb\,ug}{-Kwf + ugp} = \frac{p}{w} \frac{1}{ug - uf} \frac{-\frac{K}{p}waf + bug}{-Kwf + ugp}$$

$$= \frac{\cancel{p}}{\cancel{w}} \frac{\cancel{w}}{\cancel{p}} \frac{1}{ug - uf} \frac{-\frac{K}{p}af + \frac{u}{w}bg}{-Kf + \frac{u}{w}gp} = \boxed{\frac{1}{p} \frac{1}{ug - uf} \frac{-\frac{K}{p}af + \frac{u}{w}bg}{-\frac{K}{p}f + \frac{u}{w}g}}$$

Ultimo parametro: $\frac{P}{W}$: uso la misura del Thru, ipotizzando $\underline{\underline{T_T}} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ (T6)

$\hookrightarrow \underline{\underline{T_{M1}}} = \frac{P}{W} \underline{\underline{X_A}} \; \underline{\underline{X_B}}^{-1} \rightsquigarrow$ trovo α_1 e h_0:

$\hookrightarrow \underline{\underline{T_{M\,DUT}}} = \alpha \, \underline{\underline{X_A}} \; \underline{\underline{T_{DUT}}} \; \underline{\underline{X_B}}^{-1}$

SOLR: Short, Open, Load, Reciprocal (non thru).

Si fanno 3 misure: Short, Open, Load.

$$\Gamma_{mS} = \frac{b + \frac{K}{P} a \, \Gamma_{short}}{1 + \frac{K}{P} \Gamma_{short}} \; ; \quad \Gamma_{ML} = \dots \quad \Gamma_{mO} = \dots$$

3 standard a 1 porta. L'ultimo, "R", Reciprocal, impone la reciprocità del blocco. Ciò, con le matrici $\underline{\underline{T}}$, equivale a dire:

$$\underline{\underline{T}} = \begin{bmatrix} \frac{\Delta}{S_{21}} & \frac{S_{11}}{S_{21}} \\ \frac{-S_{22}}{S_{21}} & \frac{1}{S_{21}} \end{bmatrix} \Rightarrow \det\{\underline{\underline{T}}\} = \frac{\cancel{S_{11}S_{22}} - S_{12}S_{21}}{\cancel{S_{21}^2}} - \frac{\cancel{S_{11}S_{12}}}{\cancel{S_{21}^2}} = 1$$

$$\hookrightarrow \underline{\underline{T_{mR}}} = \alpha \, \underline{\underline{X_A}} \; \underline{\underline{T_R}} \; \underline{\underline{X_B}}^{-1} \longrightarrow \det\{\underline{\underline{T_{mR}}}\} = \alpha^2 \frac{\det\{\underline{\underline{X_A}}\} \overset{1}{\cancel{\det\{\underline{\underline{T_R}}\}}}}{\det\{\underline{\underline{X_B}}\}}$$

$$\hookrightarrow \alpha = \pm \sqrt{\frac{\det\{\underline{\underline{T_{mR}}}\} \det\{\underline{\underline{X_B}}\}}{\det\{\underline{\underline{X_A}}\}}}$$

e il segno si determina dal delay del reciprocal

LRM : Line, Reflect, Match.

La "line" permette di fer ciò:

$\underline{\underline{T}}_{mL} = \underline{\underline{T}}_A \underline{\underline{T}}_L \underline{\underline{T}}_B^{-1} \longrightarrow \boxed{\underline{\underline{T}}_B = \underline{\underline{T}}_{mL}^{-1} \underline{\underline{T}}_A \underline{\underline{T}}_L}$

$\hookrightarrow \underline{\underline{T}}_{mDUT} = \underline{\underline{T}}_A \underline{\underline{T}}_{DUT} \underline{\underline{T}}_B^{-1} = \underline{\underline{T}}_A \underline{\underline{T}}_{DUT} \underline{\underline{T}}_L^{-1} \underline{\underline{T}}_A^{-1} \underline{\underline{T}}_{mL}$

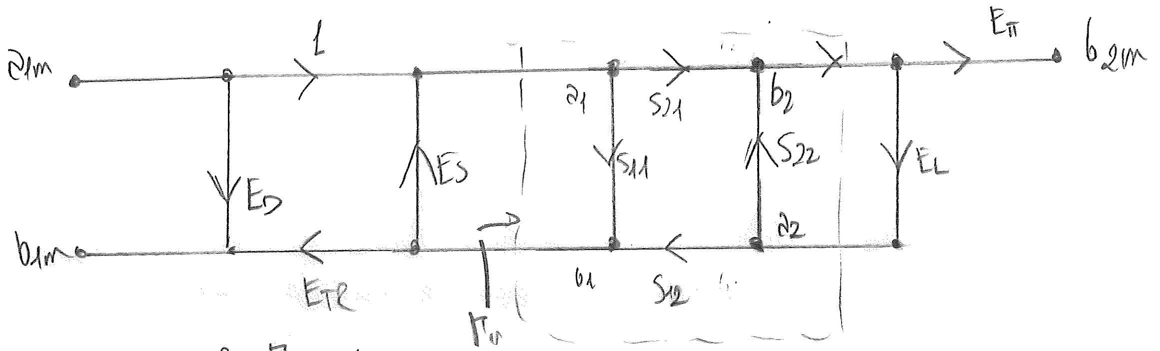
Ora, $\underline{\underline{T}}_A$ è ancora incognita, e $\underline{\underline{T}}_A = p \begin{bmatrix} \frac{k}{p} a & b \\ \frac{k}{p} & 1 \end{bmatrix}$. Per il match,

$$\Gamma_{mM_1} = e_{11} + \frac{e_{12} e_{21} \Gamma_X}{1 - e_{22}\Gamma_X} = \boxed{\frac{b + \frac{k}{p} a \Gamma_M}{1 + \frac{k}{p} \Gamma_M}}$$

$$\Gamma_{mM_2} = \frac{f + \frac{u}{w} g \Gamma_M}{1 + \frac{u}{w} \Gamma_M}$$

SOLT

Si usa un modello scattering di questo tipo:



$$\frac{b_{1m}}{a_{1m}} = E_D + \frac{1 \times \Gamma_{in\,DUT} E_{TR}}{1 - E_S \Gamma_{in\,DUT}} \qquad \Gamma_{in\,DUT} = \frac{b_1}{a_1} = S_{11} + \frac{S_{21} E_L S_{12}}{1 - S_{22} E_L}$$

$$\frac{b_{2m}}{a_{1m}} = \underbrace{\frac{1}{1 - E_S \Gamma_{in}}}_{\text{arrivo a } \Gamma_{in}} \underbrace{S_{21}}_{\text{trasmetto}} \underbrace{\frac{1}{1 - E_L S_{22}}}_{\text{II° loop}} \underbrace{E_{TT}}_{\text{fine}}$$

{ Arrivo fino a Γ_{in}, da qui "vado avanti" (S_{21}), trovo un altro anello, lo supero, e dunque E_{TT}. }

Ricordo che SOLT = Short, Open, Load, Thru.

La calibrazione si fa:

1) mettendo il match da una parte; si trova $\Gamma_{in\,DUT} = 0$

$$\begin{cases} S_{11m} = E_{DF}; \\ S_{22m} = E_{DR}; \end{cases}$$

2) mettendo short e open alle porte:

$$\begin{cases} \underbrace{\Gamma_{ms}}_{\text{noto}} = \underbrace{E_{DF}}_{\text{noto}} - \dfrac{E_{TRF}}{1+E_S} \\ \underbrace{\Gamma_{mo}}_{\text{noto}} = E_{DF} + \dfrac{E_{TRF}}{1-E_S} \end{cases}$$

2 eq in 2 incognite.

Si fa per forward & reverse.

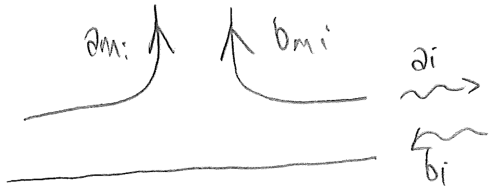
3) Metto il thru, ho:

$$S_{11m} = E_{DF} + \frac{E_{TRF} E_{LF}}{1 - E_{SF} E_{LF}} \longrightarrow \text{tutto noto tranne } E_{LF};$$

4) Con le misure di S_{11m}, S_{21m} (modello forward) e S_{22m}, S_{12m} (modello reverse) si trovano rispettivamente E_{LF}, E_{TTF}, E_{LR}, E_{TTR}.

T9

Calibrazione multiporte



Essendo il sistema lineare (4-sampler: ho 2 misure per porta):

$$\begin{cases} a_i = l_i\, b_{mi} - h_i\, a_{mi} \\ b_i = k_i\, b_{mi} - m_i\, a_{mi} \end{cases}$$

Di porte ne ho N ; dai vari a_i :

$$\hookrightarrow \begin{cases} \mathbf{a} = \mathbf{L}\, \mathbf{b}_m - \mathbf{H}\, \mathbf{a}_m \\ \mathbf{b} = \mathbf{K}\, \mathbf{b}_m - \mathbf{M}\, \mathbf{a}_m \end{cases}$$

di questa ho M misure: $[a^1_i, a^2_i, \dots, a^M_i]$

$$\begin{cases} \mathbf{A} = \mathbf{L}\, \mathbf{B}_m - \mathbf{H}\, \mathbf{A}_m \\ \mathbf{B} = \mathbf{K}\, \mathbf{B}_m - \mathbf{M}\, \mathbf{A}_m \end{cases}$$

Posso definire una relazione del tipo:

$$\mathbf{B} = \mathbf{S}\,\mathbf{A} \longrightarrow \mathbf{K}\,\mathbf{B}_m - \mathbf{M}\,\mathbf{A}_m = \mathbf{S}\,\mathbf{L}\,\mathbf{B}_m - \mathbf{S}\,\mathbf{H}\,\mathbf{A}_m$$

$$\hookrightarrow \mathbf{S}\left(\mathbf{L}\,\mathbf{B}_m - \mathbf{H}\,\mathbf{A}_m\right) = \dots \longrightarrow \mathbf{S} = \left(\mathbf{K}\,\mathbf{B}_m - \mathbf{M}\,\mathbf{A}_m\right)\left(\mathbf{L}\,\mathbf{B}_m - \mathbf{H}\,\mathbf{A}_m\right)^{-1}$$

Da prima, invece che ricavare $\mathbf{S}$, si può dire che $\mathbf{B}_m = \mathbf{S}_m\,\mathbf{A}_m$:

$$\hookrightarrow \mathbf{K}\,\mathbf{S}_m\,\cancel{\mathbf{A}_m} - \mathbf{M}\,\cancel{\mathbf{A}_m} - \mathbf{S}\,\mathbf{L}\,\mathbf{S}_m\,\cancel{\mathbf{A}_m} + \mathbf{S}\,\mathbf{H}\,\cancel{\mathbf{A}_m}$$

$$\hookrightarrow \mathbf{K}\,\mathbf{S}_m - \mathbf{M} - \mathbf{S}\,\mathbf{L}\,\mathbf{S}_m + \mathbf{S}\,\mathbf{H} = \emptyset$$

raccolgo K: $\longrightarrow \Gamma_m - \frac{M}{K} - \frac{\Gamma L \Gamma_m}{K} + \Gamma H = \emptyset$

e scalare:

(se $K \to 1$ per normalizzazione): $\Gamma_m (1 - \Gamma L) = M - \Gamma H \longrightarrow \boxed{\Gamma_m = \frac{M - \Gamma H}{1 - \Gamma L}}$

espressione simile a quella nota!

Modello 3-sampler

Ci sono 2 possibili stati per una porta:

- Stato A: porta adattata (2 misure) $\rightsquigarrow$ modello 4 sampler
- Stato B (solo misura di b_m): porta caricata $\rightsquigarrow$ modello 3 sampler

$$\longrightarrow A) \begin{cases} \tilde{\mathbf{A}} = \mathbf{L}\,\tilde{\mathbf{B}}_m - \mathbf{H}\,\tilde{\mathbf{A}}_m \\ \tilde{\mathbf{B}} = \mathbf{K}\,\tilde{\mathbf{B}}_m - \mathbf{M}\,\tilde{\mathbf{A}}_m \end{cases} \qquad B) \begin{cases} \hat{\mathbf{A}} = \mathbf{G}\,\hat{\mathbf{B}}_m \\ \hat{\mathbf{B}} = \mathbf{F}\,\hat{\mathbf{B}}_m \end{cases}$$

$\hat{\mathbf{A}}, \hat{\mathbf{B}}$ non hanno el. sulla diagonale

$$\hookrightarrow \begin{cases} \mathbf{A} = \tilde{\mathbf{A}} + \hat{\mathbf{A}} \\ \mathbf{B} = \tilde{\mathbf{B}} + \hat{\mathbf{B}} \end{cases} \rightsquigarrow \begin{cases} \mathbf{A} = \mathbf{L}\,\tilde{\mathbf{B}}_m - \mathbf{H}\,\tilde{\mathbf{A}}_m + \mathbf{G}\,\hat{\mathbf{B}}_m \\ \mathbf{B} = \mathbf{K}\,\tilde{\mathbf{B}}_m - \mathbf{M}\,\tilde{\mathbf{A}}_m + \mathbf{F}\,\hat{\mathbf{B}}_m \end{cases}$$

applico: $\underline{\underline{B}} = \underline{\underline{S}}\,\underline{\underline{A}}$

$\hookrightarrow \underline{\underline{K}}\,\tilde{\underline{\underline{B}}}_m - \underline{\underline{M}}\,\tilde{\underline{\underline{A}}}_m + \underline{\underline{F}}\,\hat{\underline{\underline{B}}}_m = \underline{\underline{S}}\,\underline{\underline{L}}\,\tilde{\underline{\underline{B}}}_m - \underline{\underline{S}}\,\underline{\underline{H}}\,\tilde{\underline{\underline{A}}}_m + \underline{\underline{S}}\,\underline{\underline{G}}\,\hat{\underline{\underline{B}}}_m$

Note:

- modello a 4 sampler necessita di $4N-1$; a 3, $6N-1$ (2 porte con degeneri).
- per usare std a 2 porte si deve scalarizzare.
- dynamic calibration: calcolare via software una seq. di std tale da avere le matrici $\underline{\underline{L}}, \underline{\underline{H}}, \underline{\underline{K}}, \underline{\underline{M}}$ definite.
- Se ho 4 sampler, ho lo stato AA, e posso applicare tra le 2 porte, TRL/TSD/ALTD;
- Se NO, posso fare AA, AB, BA
- La storia dei 2 gradi di libertà (p e w): dato un "non reciprocal thru", delle 8 eq 6 son l.i. $\longrightarrow$ thru loop, $6+4 = 10$ eq. l.i.

$\hookrightarrow$ va bene con connettori senza sesso.

$\hookrightarrow$ RICORDA: devi fissare Z0: offset short o load o LOAD.

$\Delta\Gamma \triangleq \Gamma_m - \Gamma_x$; $\Gamma_m = E_D + \frac{E_T\Gamma_x}{1-E_S\Gamma_x}$; $\Delta\Gamma = E_D + \frac{E_T\Gamma_x - \Gamma_x + E_S\Gamma_x^2}{1-E_S\Gamma_x}$;

per $\Gamma_x \to 0$, $\Delta\Gamma \longrightarrow E_D + \Gamma_x(E_T - 1)$

per $\Gamma_x \to 1$, derivo:

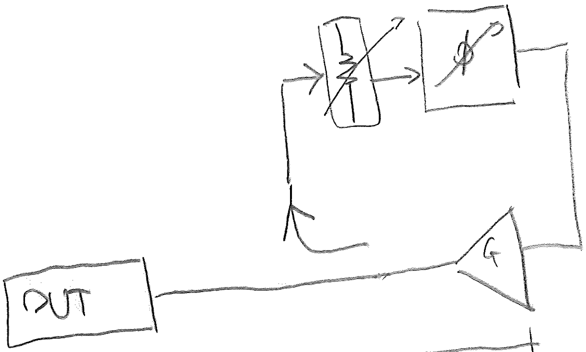
$$\frac{\partial \Delta\Gamma}{\partial \Gamma_x} = \frac{(E_T - 1 + 2E_S\Gamma_x)(1-E_S\Gamma_x) + E_S(E_T\Gamma_x - \Gamma_x + E_S\Gamma_x^2)}{(1-E_S\Gamma_x)^2} =$$

$$= E_T - \cancel{E_S E_T \Gamma_x} - 1 + \cancel{E_S\Gamma_x} + 2E_S\Gamma_x - \cancel{2E_S^2\Gamma_x^2} + \cancel{E_S E_T\Gamma_x} - \cancel{E_S\Gamma_x} + \cancel{E_S^2\Gamma_x^2}$$

$$\simeq E_T + 2E_S\Gamma_x - 1 \longrightarrow$$

Load pull attivo - analisi / calcoli.

Lo schema di principio è:



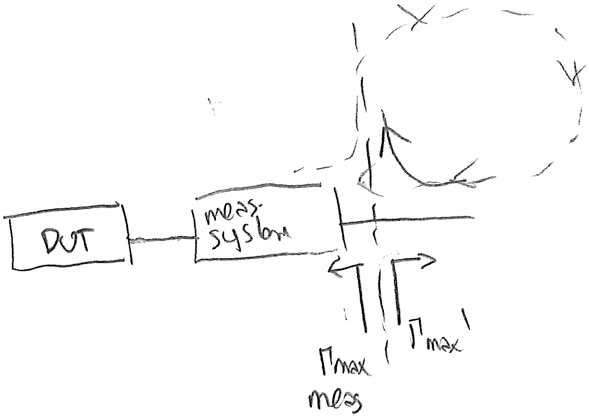
$$\begin{cases} T = GA\exp(-j\phi) I \quad (\text{loop gain}) \\ \Gamma = CGA\exp(-j\phi); \\ L^2 = S_{12}S_{21}; \\ D = \frac{I}{C}; \end{cases}$$

T critico: 1; $\boxed{\Gamma_{max} = 1 = xL^2C} \longrightarrow x = \frac{1}{L^2C}$

$\hookrightarrow 1 = GA\exp(-j\phi) I \longrightarrow I = \frac{1}{GA\exp(-j\phi)} \triangleq \frac{1}{X}$.

$\hookrightarrow D = \frac{1}{xC}; \longrightarrow \frac{1}{\frac{1}{L^2C}C} = L^2 \Rightarrow \boxed{D \geq L^2}$ (oppure, $\Gamma_{max} = xL^2C$, ricavo $x = \frac{1}{DC} \longrightarrow \Gamma_{max} = \frac{1}{DC}L^2C = \frac{L^2}{D}$).

Loop critico per la stabilità:



$$\Gamma_{max\,meas} = S_{11} + \frac{S_{12}S_{21}\Gamma_{DUT}}{1 - S_{22}\Gamma_{DUT}}$$

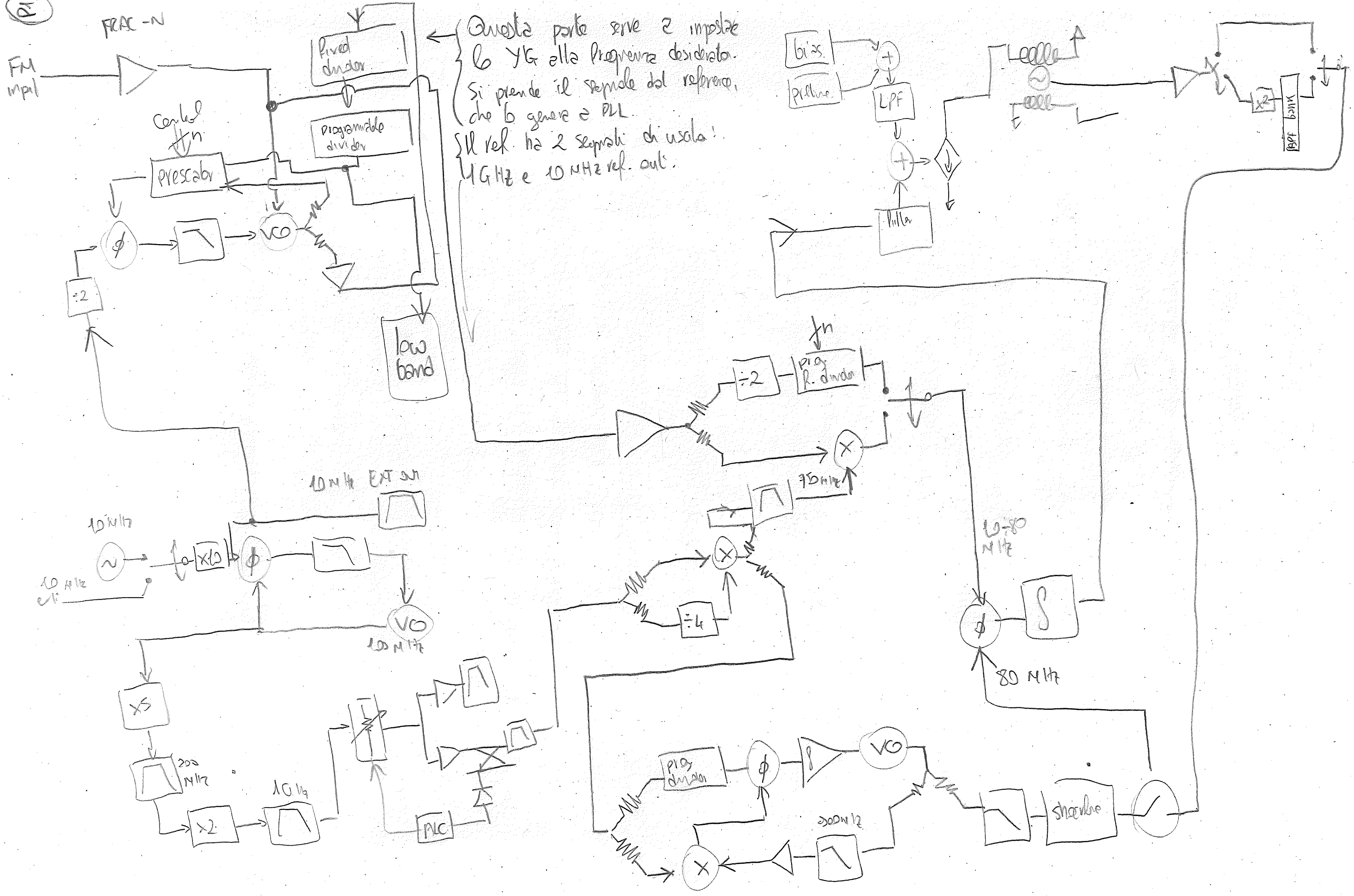
dove, al più, $\Gamma_{DUT} = 1$;

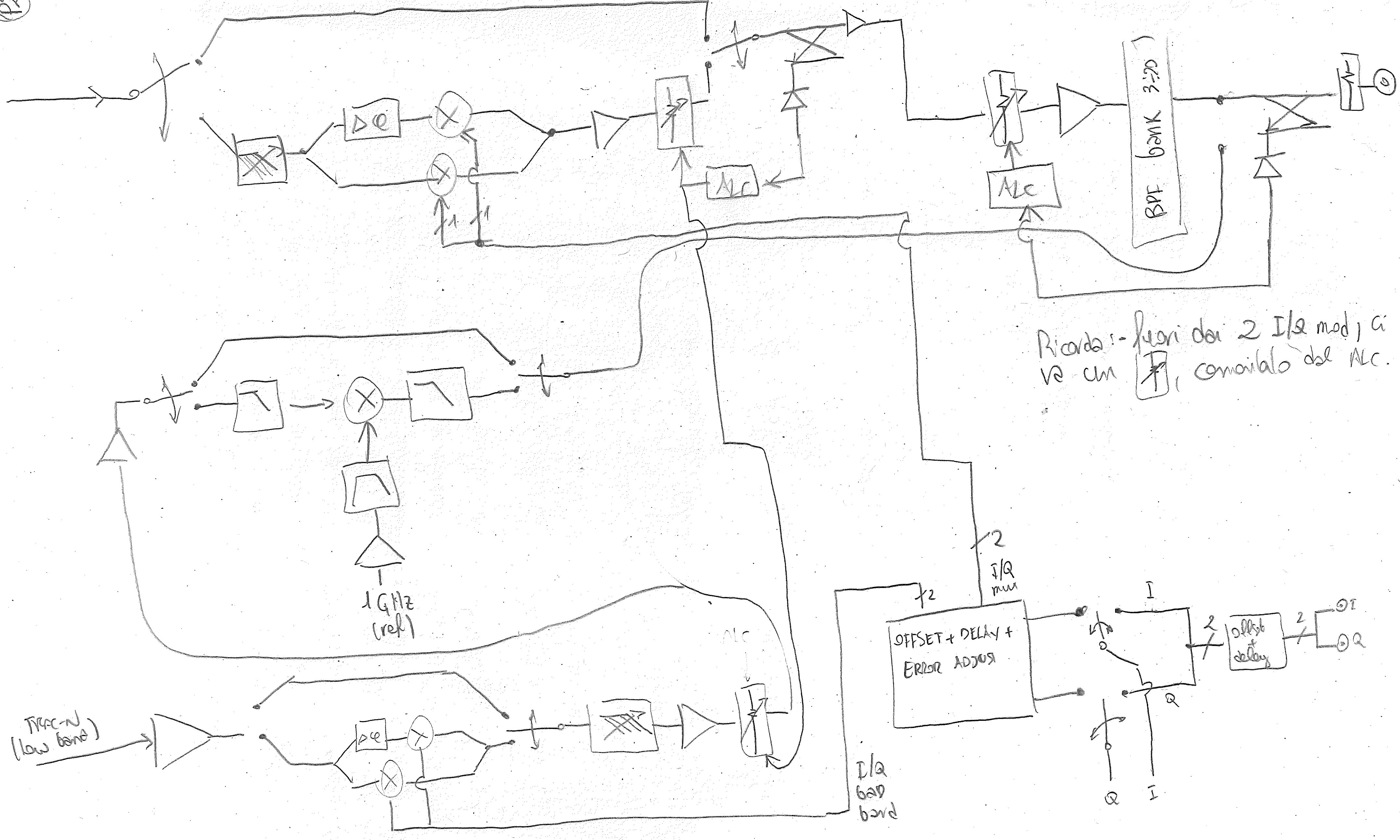
$$\Gamma_{max}' = \frac{1}{L^2}$$

$$\hookrightarrow \Gamma_{max\,meas}\Gamma_{max}' = \left(S_{11} + \frac{\overbrace{\cancel{S_{21}S_{12}}}^{L^2}\cancel{\Gamma_{DUT}}}{1 - S_{22}\cancel{\Gamma_{DUT}}}\right)\left(\frac{1}{L^2}\right)$$

$$\simeq \frac{S_{11}}{L^2} + \frac{1}{1 - S_{22}}$$

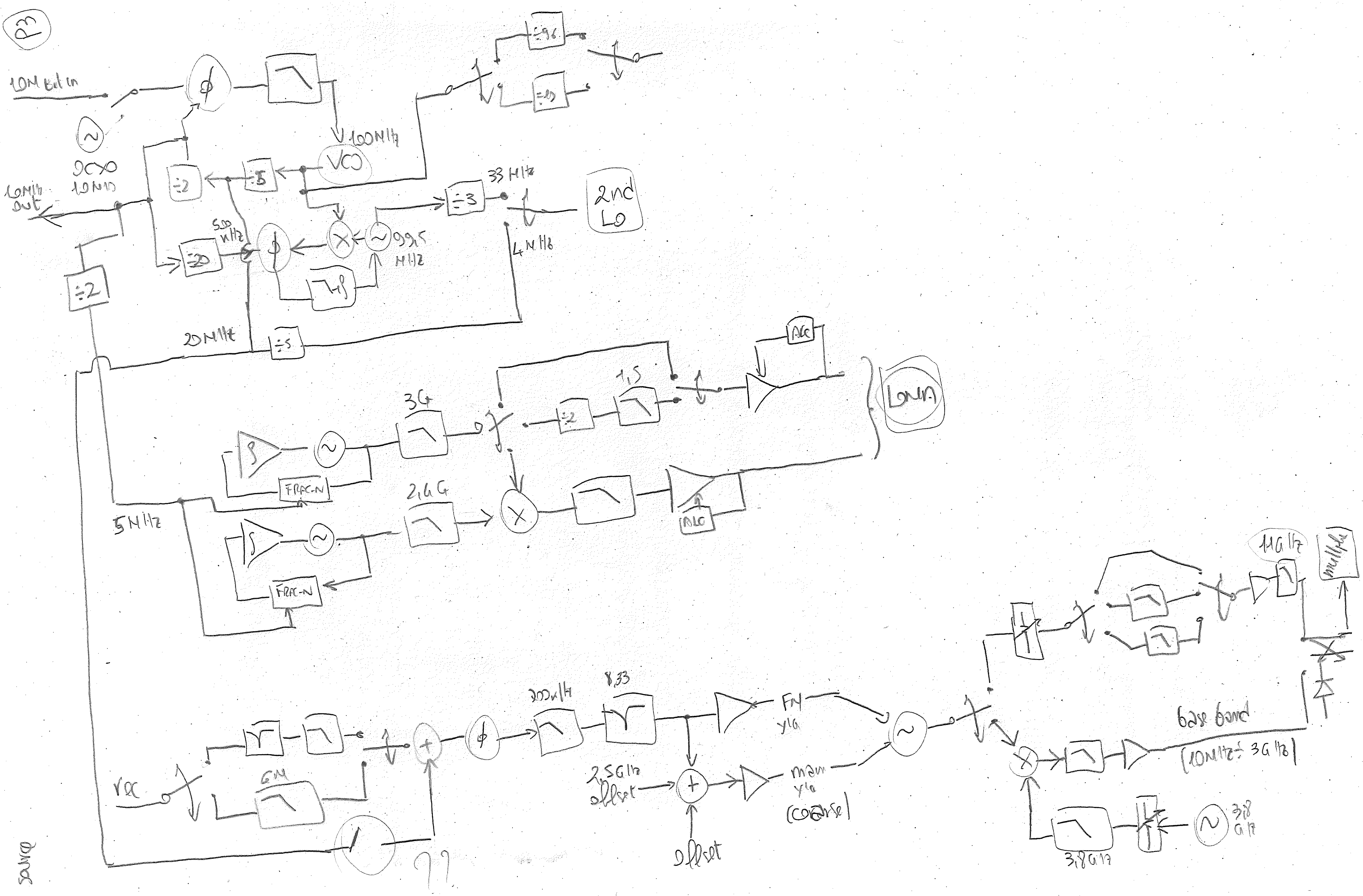
$\longrightarrow$ il problema è il disadattamento!

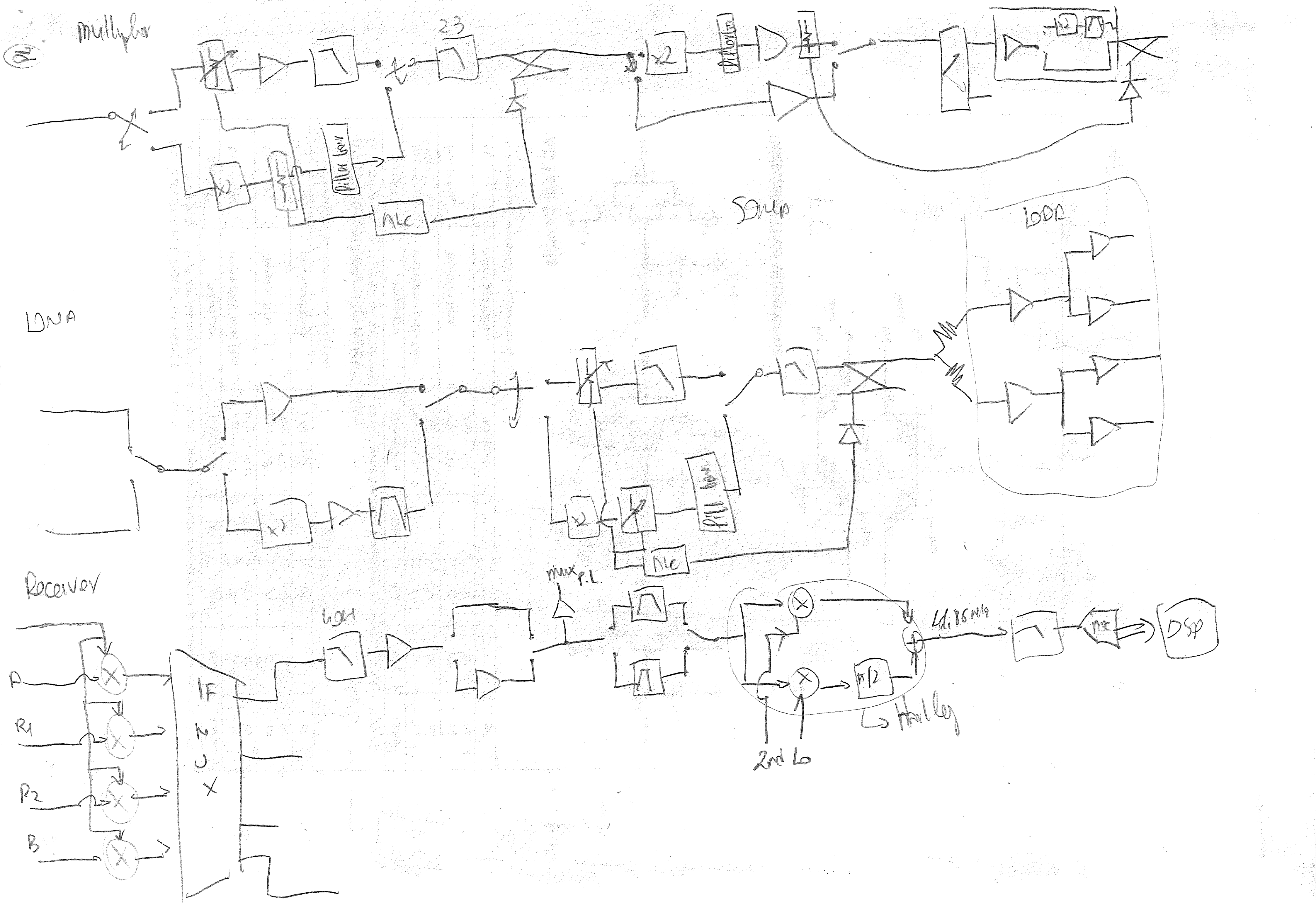

FRAC-N
FM input
Control
fn
Prescaler
Fixed divider
Programmable divider
VCO
÷2
low band
Questa parte serve a impostare
la YIG alla frequenza desiderata.
Si prende il segnale dal reference,
che lo genera a PLL.
Il ref. ha 2 segnali di uscita!
1GHz e 10 MHz ref. out.
bias
Pulling
LPF
Pulla
x2
BPF bank
fn
÷2
Prog. R. divider
75 MHz
10 MHz EXT out
10 MHz
10 MHz ext
x10
VCO
100 MHz
x5
200 MHz
x2
1GHz
ALC
÷4
10-80 MHz
80 MHz
prog. divider
VCO
300 MHz
Shoreline

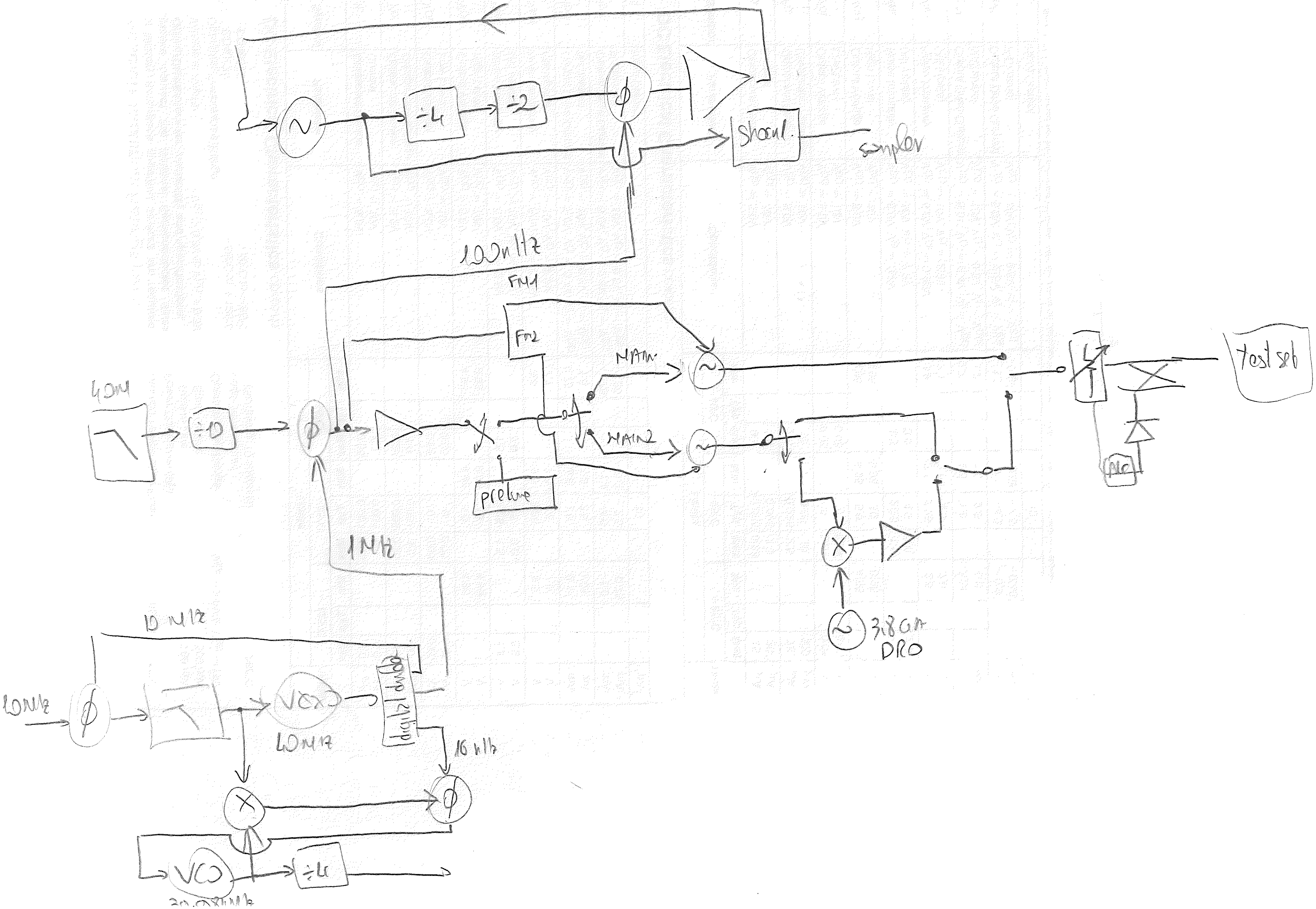


Ricorda: - fuori dai 2 I/Q mod, ci va un [variable attenuator symbol], comandato dal ALC.

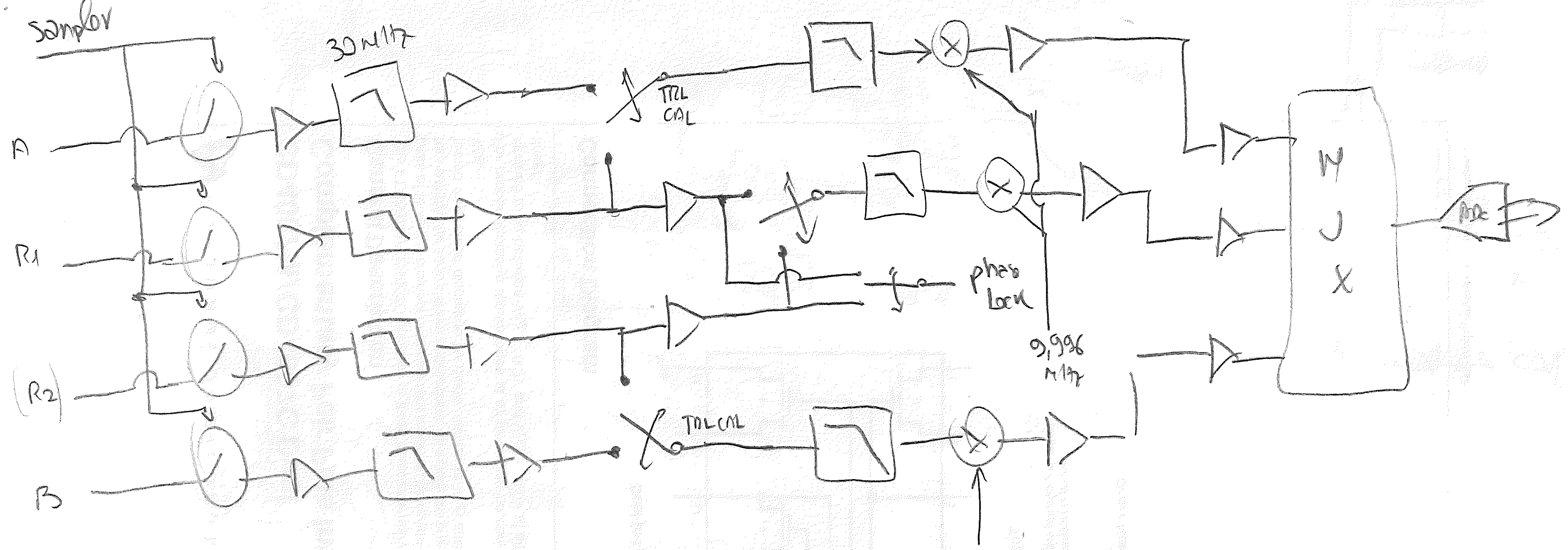
PNA source


P3
10M ext in
OCXO
10 MHz
10MHz out
÷2
÷5
÷20
500 MHz
100 MHz
VCO
99.5 MHz
÷3
33 MHz
2nd LO
4 MHz
20 MHz
÷96
÷10
5 MHz
FRAC-N
3G
2.6G
÷2
1.5
ALC
LO/RA
8.33
200 MHz
FM
yig
main
yig
(coarse)
2.5 GHz
offset
offset
vco
6M
??
base band
(10 MHz ÷ 3 GHz)
3.8 GHz
3.8 GHz
1 GHz
multiple


P4
Multiplier
23
x2
Filter bank
ALC
SSPA
LODA
LNA
Filt. bank
ALC
Receiver
A
R1
R2
B
IF
MUX
max P.L.
2nd Lo
Hartley
DSP


÷4
÷2
sampler
100MHz
FM1
FM2
MAIN
MAIN2
1MHz
10MHz
10MHz
VCXO
VCO
3.8GHz
DRO
Test set

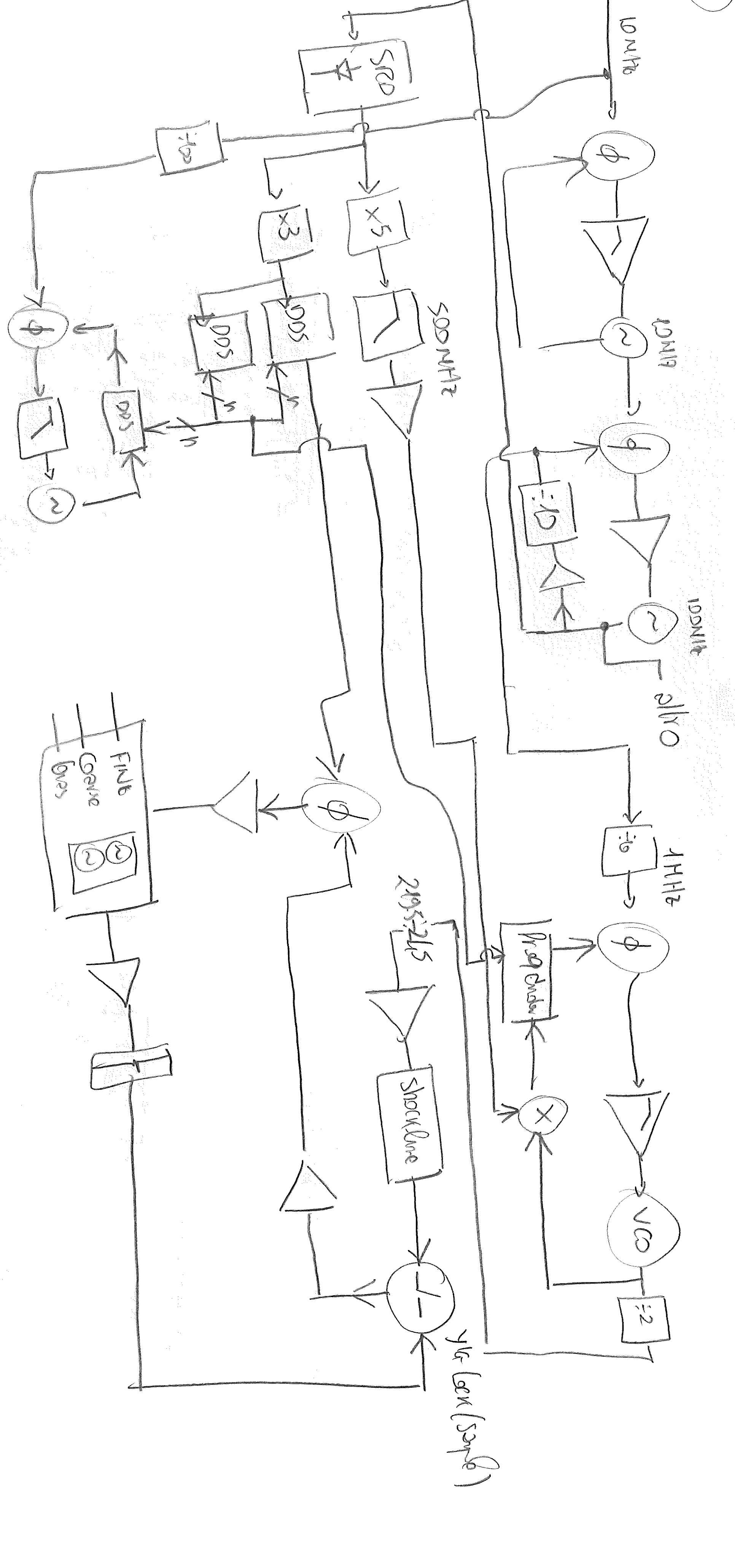
8720



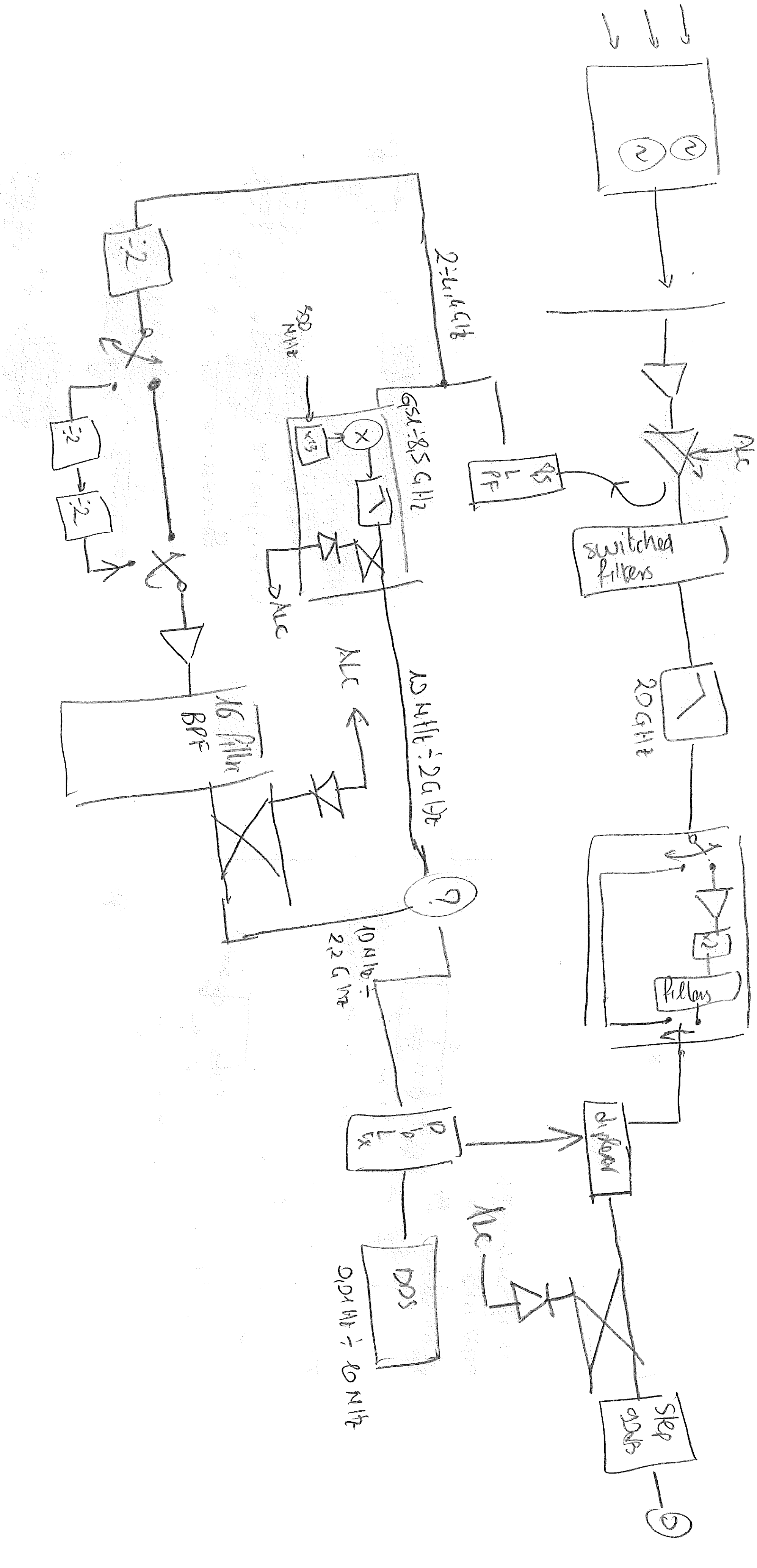
sampler
30 MHz
A
R1
R2
B
TRL CAL
TRL CAL
phase lock
9,996 MHz
MUX
ADC

MG3692

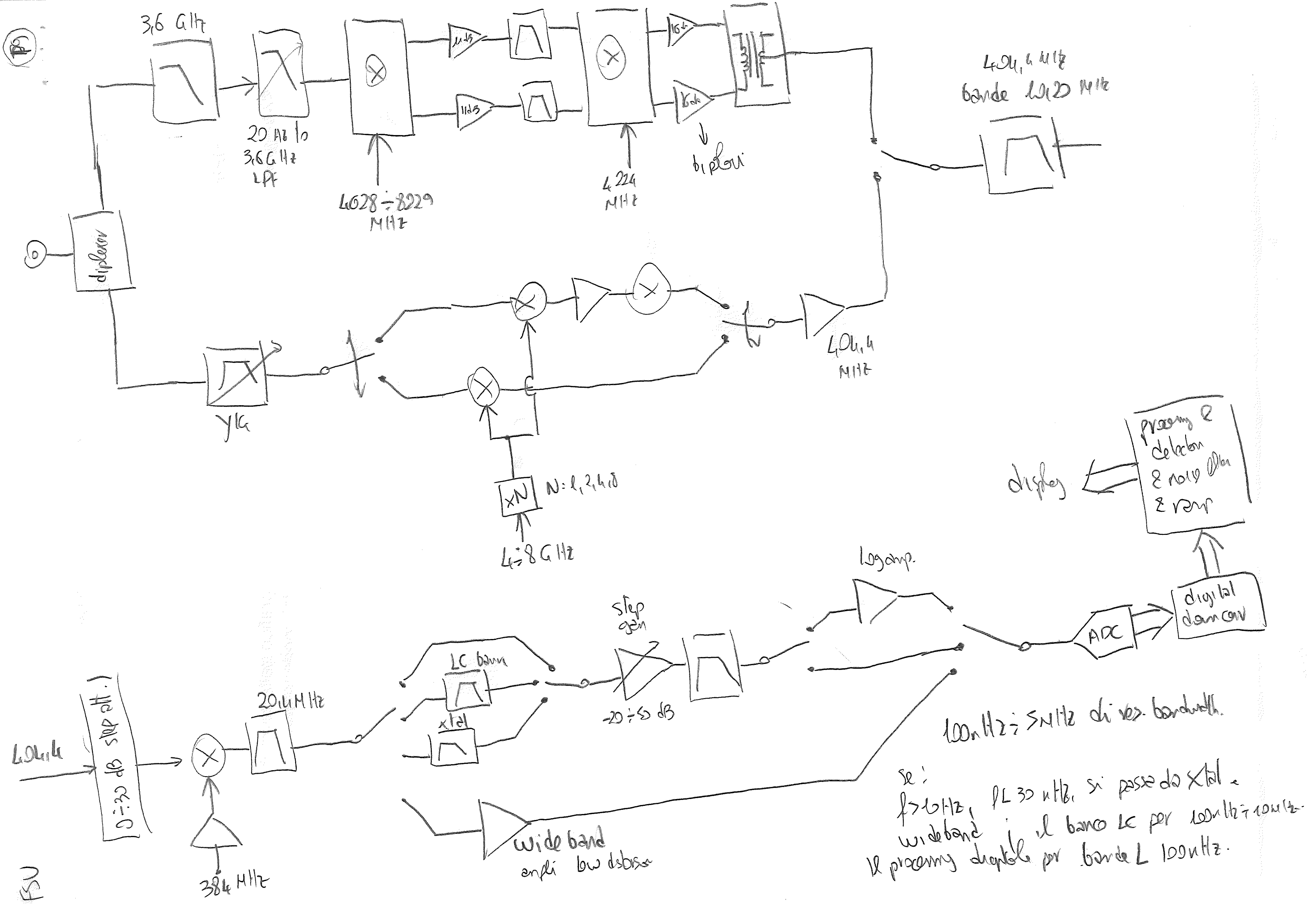
P7



10MHz
SRD
÷10
×3
×5
DDS
DDS
DDS
500MHz
10MHz
100MHz
÷D
1MHz
Prog Divider
VCO
÷2
Shockline
Fine
Coarse

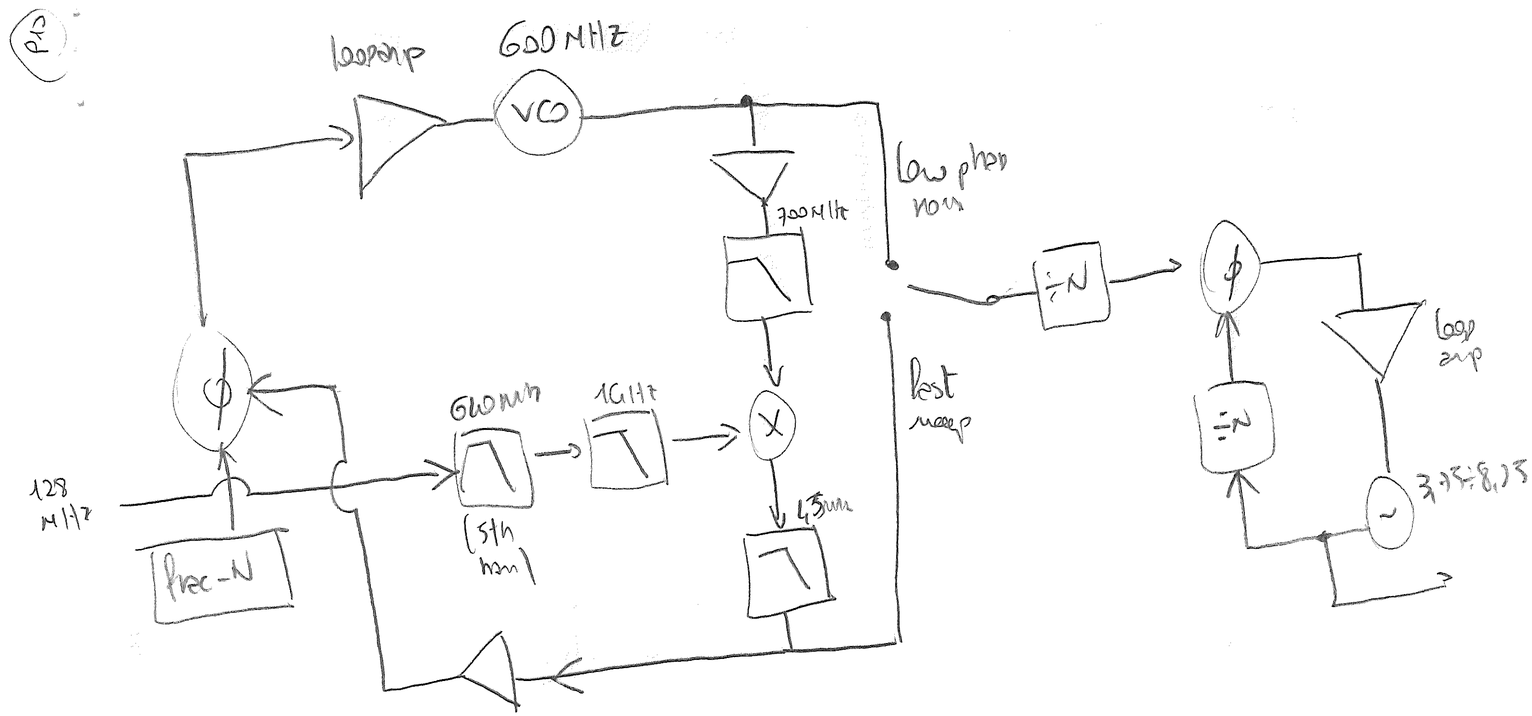

switched filters
20 GHz
ALC
2÷4.4 GHz
500 MHz
10 MHz ÷ 2 GHz
16 filter BPF
10 MHz ÷ 2.2 GHz
DDS
0.01 Hz ÷ 10 MHz
diplexer
filters
step 90dB

R&S FSU



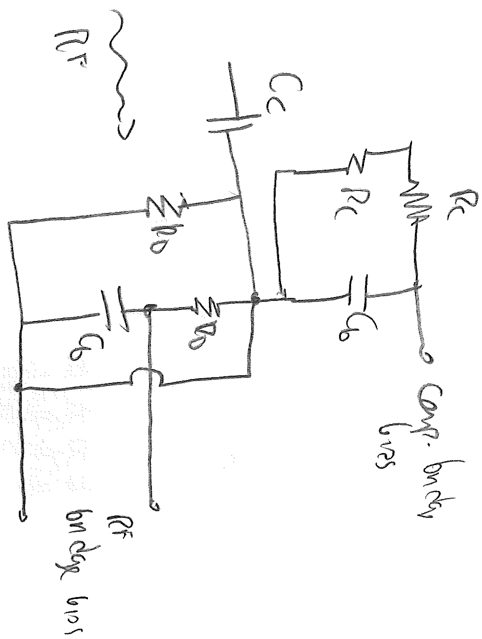
100 kHz ÷ 5 MHz di res. bandwidth.

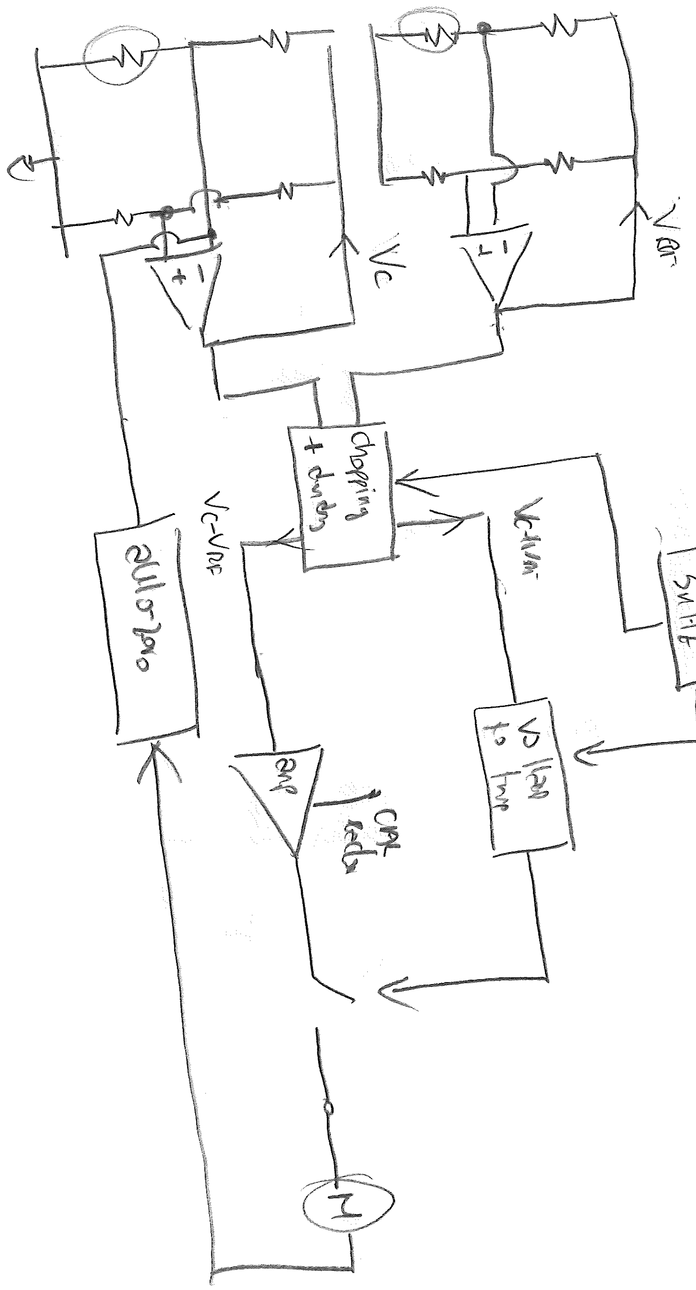
se:
f > 6 kHz, RL 30 kHz, si passa da xtal e wideband; il banco LC per 100 kHz ÷ 10 MHz.
Il processing digitale per banda L 100 kHz.



P13
loopamp
600 MHz
VCO
700 MHz
low phase noise
fast sweep
128 MHz
Frac-N
φ
600 MHz
(5th harm)
1 GHz
X
4.5 GHz
÷N
φ
loop amp
÷N
~
3.75÷8.25

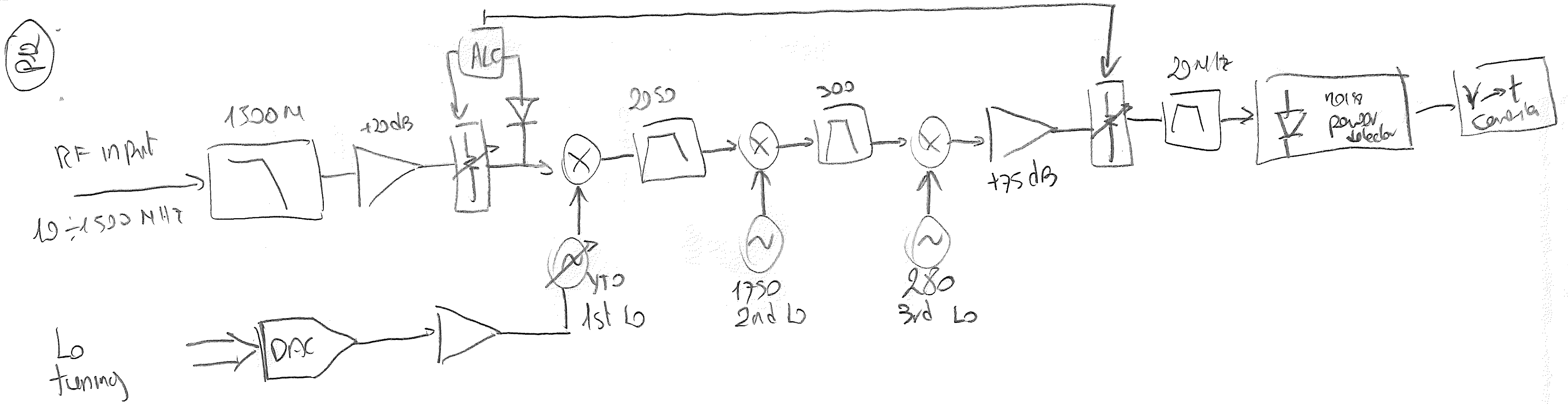
432A power motor





E8970 Noise figure meter | noise measurements theory

P12



Un po' di teoria:

$$SNR \triangleq \frac{P_{signal}}{P_{noise}} \longrightarrow SNR_{out} = \frac{P_{out}}{G N_{in} + N_{ADD\,out}} = \frac{\cancel{G} P_{in}}{\cancel{G}(N_{in} + N_{ADD\,in})} = \frac{P_{in}}{N_{in} + N_{ADD\,in}} \quad ; \quad SNR_{in} = \frac{P_{in}}{N_{in}}$$

$$\hookrightarrow F = \frac{SNR_{in}}{SNR_{out}} = \frac{N_{in} + N_{ADD\,in}}{N_{in}} = \left\{1 + \frac{N_{ADD}}{N_{in}}\right\} \equiv 1 + \frac{T_{eq}}{T_{eq\,in}} = 1 + \frac{T_{eq\,DUT}}{T_{environmental}\,(T_0)}$$

questa perché:

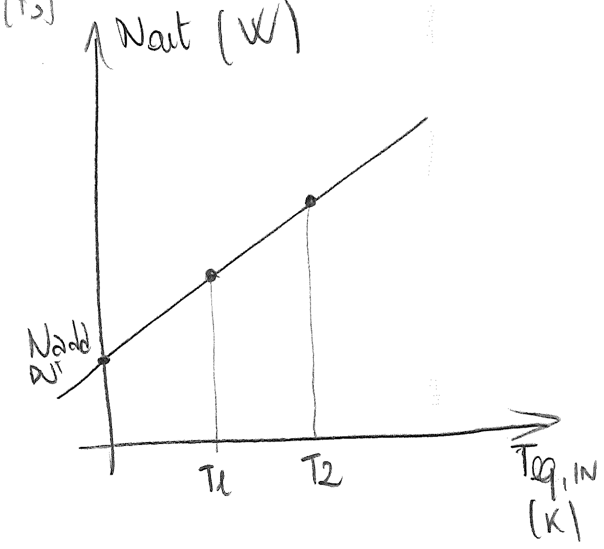
$$F = 1 + \frac{N_{add,in}}{N_{in}}$$

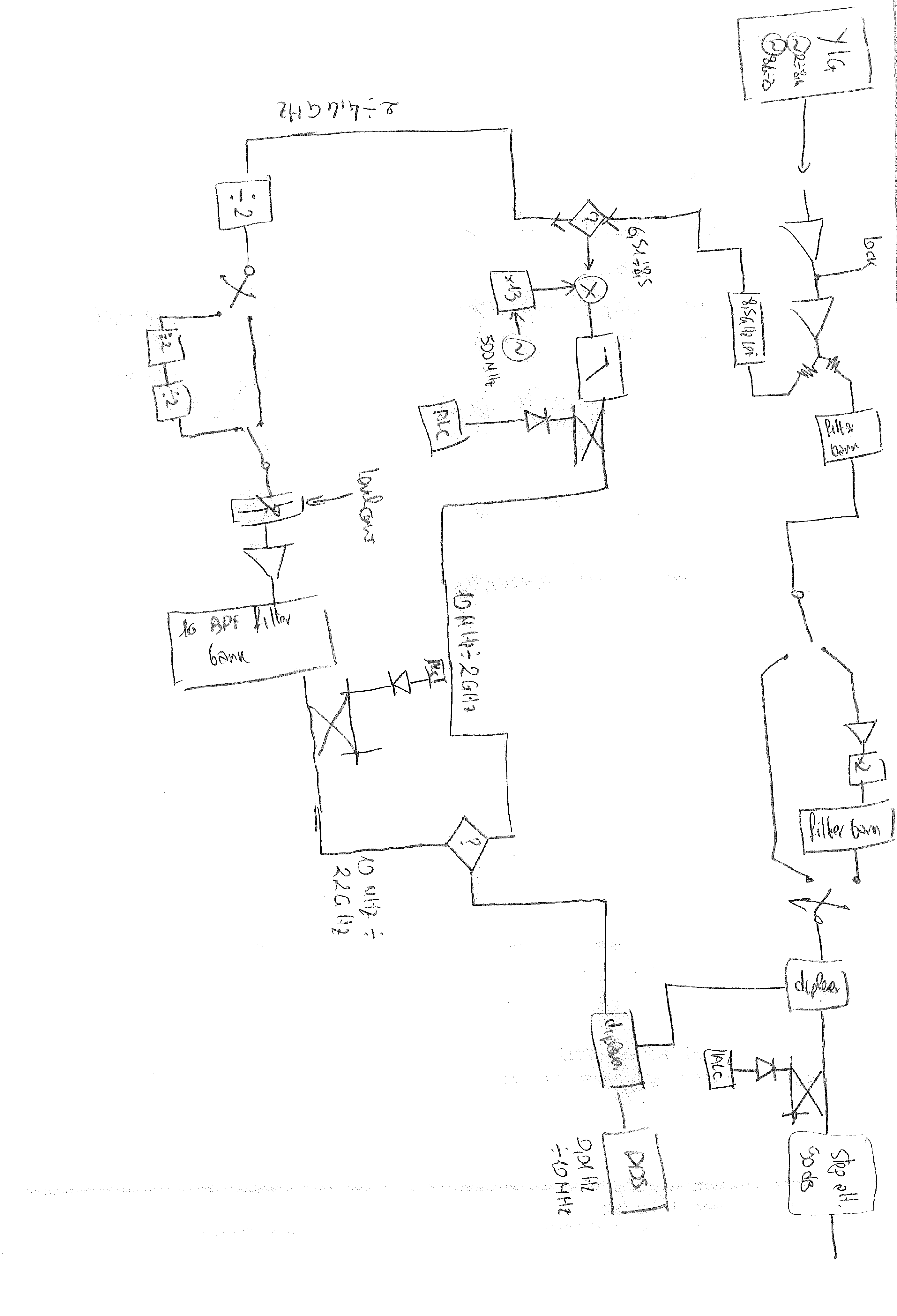
N sono potenze; posso dire che: $N = K_B T$

$$\hookrightarrow \boxed{F = 1 + \frac{T_{eq}}{T_0}} \longrightarrow \boxed{T_{eq} = T_0 (F-1)}$$

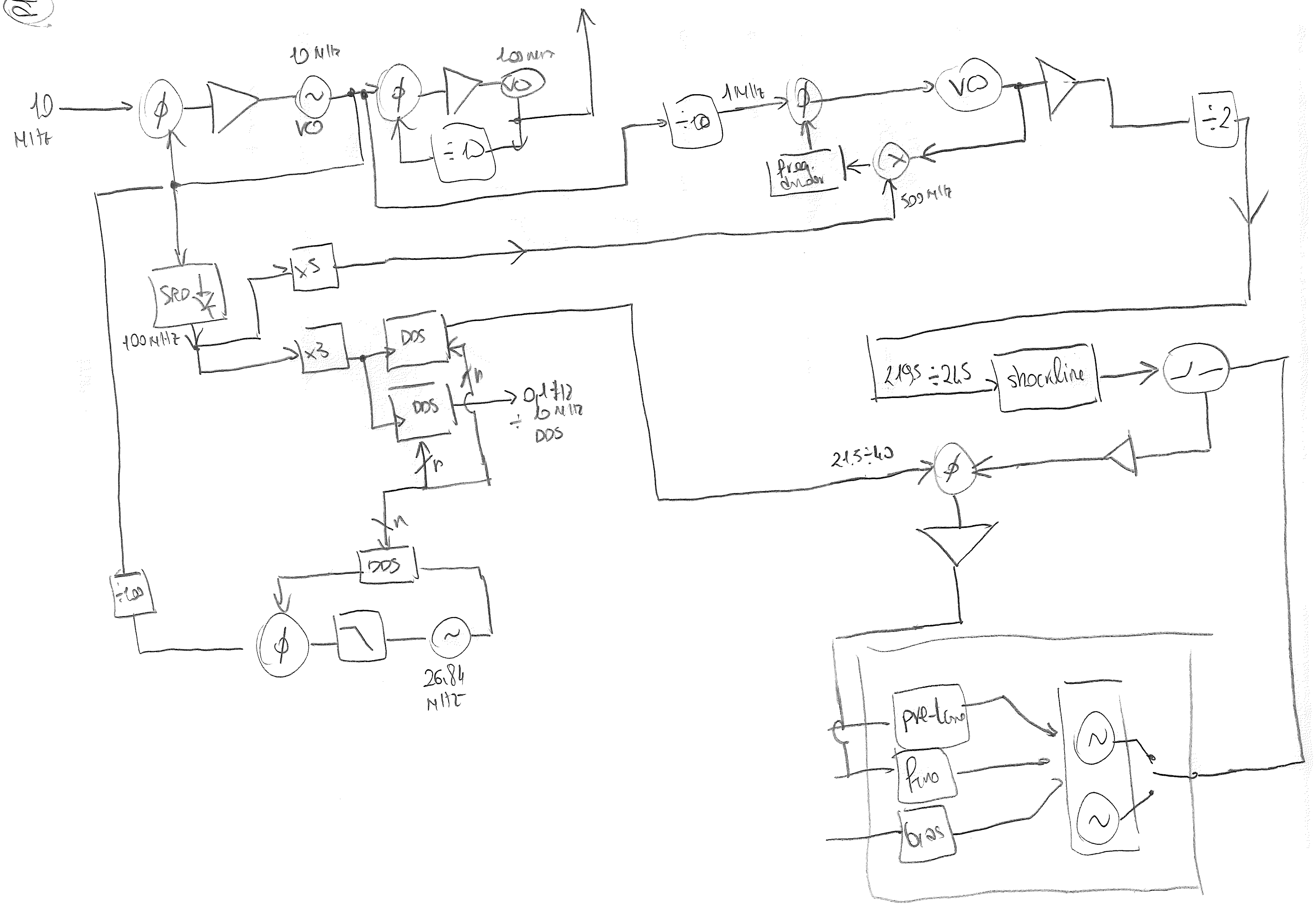
; posso dire che:

$$N_{out} = G(N_{in} + N_{add,in}) = (N_{add,in} + K_B B T_{eq,in}) G \Rightarrow \underbrace{\frac{N_{out}}{K_B B}}_{T_{eq\,out}} = \underbrace{T_{eq\,DUT}}_{costante} + \underbrace{T_{eq\,IN}}_{variabile}$$




YIG
lock
8.5 GHz LPF
filter bank
6.5÷8.5
x13
300 MHz
ALC
÷2
level cont
16 BPF filter bank
10 MHz ÷ 2 GHz
10 MHz ÷ 22 GHz
x2
filter bank
diplex
ALC
DDS
step att. 50 dB

P14



10 MHz
VO
10 MHz
100 MHz
VO
÷10
÷10
1 MHz
VO
freq. divider
500 MHz
÷2
SRD
100 MHz
×5
×3
DDS
DDS
0,1 Hz ÷ 6 MHz DDS
DDS
÷100
26,84 MHz
21.5 ÷ 40
21.95 ÷ 21.5
shockline
pre-tune
fune
bias

PNA Source

P15