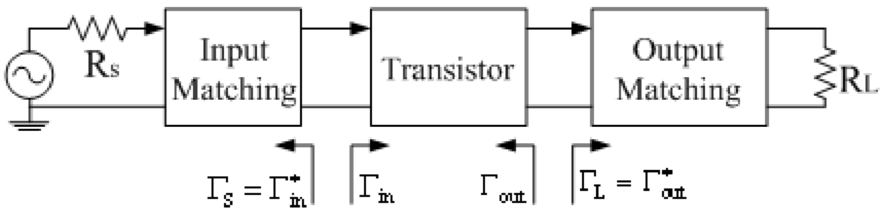
2025 RF Circuit Design HW-6　　2025/05/5

射頻或微波放大器分兩類，第一類是低雜訊放大器，另一類是最佳功率增益放大器，設計工作實際上就是要設計輸入與輸出兩匹配電路(Matching Circuits)如下圖所示，使達到特定的匹配，前者實際上就是要設計輸入匹配電路(Matching Circuits)在最佳雜訊點；而後者兩匹配電路是要將電晶體的輸入阻抗與前級阻抗 Rs 匹配，同時輸出阻抗與外加負載阻抗 RL 匹配，達到最佳功率增益。



(A) 低雜訊放大設計

已知雜訊指數如下公式

$$F = F_{min} + \frac{4r_n\left|\Gamma_s - \Gamma_{s,opt}\right|^2}{\left(1-\left|\Gamma_s\right|^2\right)\left|1+\Gamma_{s,opt}\right|^2}$$

定義雜訊指數F_i的參數 N_i

$$N_i \equiv \frac{\left|\Gamma_s - \Gamma_{s,opt}\right|^2}{\left(1-\left|\Gamma_s\right|^2\right)}$$

$$\therefore F_i = F_{min} + \frac{4r_n N_i}{\left|1+\Gamma_{s,opt}\right|^2}$$

一般最佳雜訊指數 F_{min}、 $r_n=R_n/50$、及 $\Gamma_{S,opt}$ 由廠商提供。任一雜訊參數 Ni 對應一 Fi，而且滿足圓方程式

$$\therefore \left|\Gamma_s - \frac{\Gamma_{s,opt}}{\left(1+N_i\right)}\right|^2 = \frac{N_i^2 + N_i\left(1-\left|\Gamma_{s,opt}\right|^2\right)}{\left(1+N_i\right)^2}$$

$$圓心 = \frac{\Gamma_{s,opt}}{\left(1+N_i\right)}$$

並且

$$半徑 = \frac{\left[N_i^2 + N_i\left(1-\left|\Gamma_{s,opt}\right|^2\right)\right]^{1/2}}{\left(1+N_i\right)}$$

低雜訊放大的設計程序是先決定 Γ_s 後再帶入

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s} = \Gamma_L^*$$

由 Γ_S 及 Γ_L 就可設計輸入及輸出匹配電路。

(B) 最佳功率增益設計

選擇電晶體最重要的兩件事情是穩定度 K>1 以及能夠提供最佳的增益 MAG。

Rollett Stability Factor K，

$$K = \frac{1-|S_{11}|^2 - |S_{22}|^2 + \Delta^2}{2|S_{12}S_{21}|}$$ K> Inherent Stability

$$\mathrm{MAG} = \frac{|S_{21}|}{|S_{12}|}\left(K - \sqrt{K^2 - 1}\right)$$

電晶體輸入端的反射係數為

$$\Gamma_{in} = s_{11} + \frac{s_{12}s_{21}\Gamma_L}{1-\Gamma_L s_{22}}$$

電晶體輸出端的反射係數為

$$\Gamma_{out} = s_{22} + \frac{s_{12}s_{21}\Gamma_s}{1-\Gamma_s s_{11}}$$

在互為共軛匹配的條件下可得最佳的反射係數與 S 參數關係

$\Gamma_{sopt} = \dfrac{B_1 - \sqrt{B_1^2 - 4\|C_1\|^2}}{2C_1}$ $\Gamma_{Lopt} = \dfrac{B_2 - \sqrt{B_2^2 - 4\|C_2\|^2}}{2C_2}$	$B_1 = 1 + \|S_{11}\|^2 - \|S_{22}\|^2 - \|\Delta\|^2$ $B_2 = 1 + \|S_{22}\|^2 - \|S_{11}\|^2 - \|\Delta\|^2$ $C_1 = S_{11} - S_{22}^*\Delta$ $C_2 = S_{22} - S_{11}^*\Delta$ $\Delta = S_{11}S_{22} - S_{12}S_{21}$

Available power gain G_A

$$\begin{aligned} G_A &= \frac{\text{Power Available from the Amplifier}}{\text{Power Available from the Source}} \\ &= G_T\big|_{\Gamma_L = \Gamma_{out}^*} \\ &= \frac{|S_{21}|^2\left(1-|\Gamma_s|^2\right)}{\left(1-|\Gamma_{out}|^2\right)|1-S_{11}\Gamma_s|^2} \end{aligned}$$

射頻放大器的增益有多種定義，其中與實際網路分析儀量測符合的是 Transducer Gain G_T

$$\begin{aligned} G_T &= \frac{\text{Power Delivered to the Load}}{\text{Available Power from the Source}} \\ &= \frac{\left(1-|\Gamma_L|^2\right)|S_{21}|^2\left(1-|\Gamma_S|^2\right)}{|1-\Gamma_L S_{22}|^2\,|1-S_{11}\Gamma_S|^2} \end{aligned}$$

今已知有一個微波的電晶體 **2N6680 GaAs FET 6GHz** 其[S]參數及雜訊指數如下表所列:

S-Parameter	Noise Parameters
S_{11}=0.641/-171.3°	F_{min}=2.9dB
S_{12}=0.057/16.3°	R_n=9.42Ω
S_{21}=2.058/28.5°	$\Gamma_{S,opt}$=0.542/141°
S_{22}=0.572/-95.7°	

請同學

(1) 用 MATLAB 等軟體(a)建立程式計算上面所提兩種電路所需 Γ_S、Γ_L，NF、及 G_T，(b)並繪出 NF=3、4、5dB 的等雜訊圓。

(2) 利用微條線匹配技術設計兩匹配電路，

(3) 利用微波軟體(ADS)驗證下表結果。

本習題結論:低雜訊放大獲得低雜訊，但付出代價是低增益及高輸入反射係數。

2N6680 GaAs FET 6GHz					
Γ_S (Mag/Ang)	Γ_L (Mag/Ang)	NF(dB)	G_T(dB)	Input SWR	Output SWR
0.542/141	0.575/104	**2.90**	9.33	3.82:1	1.00:1
0.762/177	0.718/104	4.44	**11.38**	1.00:1	1.00:1

1. 用傳輸線匹配可參考老師的書，為方便先提供下列公式供大家參考

2.

$$Z(d) = Z_o \frac{Z_L + jZ_o \tan\beta d}{Z_o + jZ_L \tan\beta d}$$

(1) if $Z_L = \infty$ = Open and $d = \lambda/8$

$$Z(d) = Z_o \frac{Z_L}{jZ_L} = -jZo$$

$\lambda/8$ Open-ended TL as Capacitance

(2) if $Z_L = \infty$ = Open and $d = 3\lambda/8$

$$Z(d) = Z_o \frac{Z_L}{-jZ_L} = +jZo$$

$3\lambda/8$ Open-ended TL as Inductance

(3) if $d = \lambda/4$, $\tan\beta d = \infty$

$$Z(d) = Z_o \frac{jZ_o}{jZ_L} = \frac{Z_o^2}{Z_L}$$

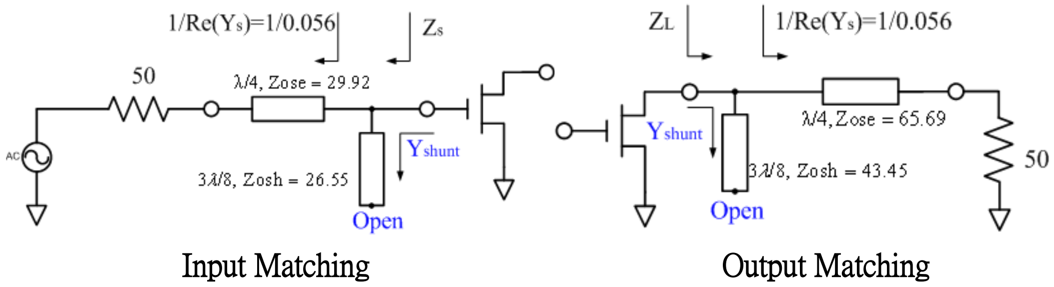
$$Z(d) \times Z_L = Z_o^2$$

Quarter Wavelength TL
as impedance Transformer

(4) if $d = \lambda/4$, and $Z_L = 0$

$$Z(d) = Z_o \frac{0 + jZ_o \tan\beta d}{Z_o + j0\tan\beta d} = \infty \text{ (Open Circuit)}$$

3. 參考設計



Γs (Mag/Ang)	ΓL (Mag/Ang)	NF(dB)	G_T(dB)	Input SWR	Output SWR
0.614/160	0.627/106	3.14	10.55	2.28:1	1.00:1

clc; clear; Z0=50; S11=0.641*exp(i*(-171.3)*pi/180); S12=0.057*exp(i*(16.3)*pi/180); S21=2.058*exp(i*(28.5)*pi/180); S22=0.572*exp(i*(-95.7)*pi/180); S=[S11 S12;S21 S22] Fmin=2.9;Rn=9.42; rn=Rn/Z0 Tsmin=0.541*exp(i*141*pi/180) Tomin=S22+((S12*S21*Tsmin)/(1-(Tsmin*S11))) TLmin=conj(Tomin) MTL1=[abs(TLmin) angle(TLmin)*180/pi] Ga1=(abs(S21)^2*(1-abs(Tsmin)^2))/((1-abs(Tomin)^2)*abs(1-S11*Tsmin)^2) Zs1=(1+Tsmin)*Z0/(1-Tsmin) Zo1=(1+Tomin)*Z0/(1-Tomin) ZL1=(1+TLmin)*Z0/(1-TLmin) Delta=(S11*S22)-(S12*S21) B1=1+abs(S11)^2-abs(S22)^2-abs(Delta)^2; B2=1-abs(S11)^2+abs(S22)^2-abs(Delta)^2; C1=S11-conj(S22)*Delta;	S = -0.6336 - 0.0970i 0.0547 + 0.0160i 1.8086 + 0.9820i -0.0568 - 0.5692i rn = 0.1884 Tsmin = -0.4204 + 0.3405i Tomin = -0.1438 - 0.5566i TLmin = -0.1438 + 0.5566i MTL1 = 0.5749 104.4851 Ga1 = 8.5811 Zs1 = 16.5761 +15.9575i Zo1 = 20.6887 -34.3992i ZL1 = 20.6887 +34.3992i Delta = -0.1024 + 0.2835i A = 0.9928 + 0.0000i 0.8254 + 0.0000i -0.4781 - 0.0226i -0.0942 - 0.3796i

C2=S22-conj(S11)*Delta;	Tsmax =
A=[B1 B2;C1 C2]	-0.7611 + 0.0359i
	TLmax =
Tsmax=(B1-sqrt(B1^2-4*(abs(C1)^2)))/(2*C1)	-0.1731 + 0.6972i
TLmax=(B2-sqrt(B2^2-4*(abs(C2)^2)))/(2*C2)	MTS2 =
Tomax=conj(TLmax)	0.7619 177.2990
MTS2=[abs(Tsmax) angle(Tsmax)*180/pi]	MTL2 =
MTL2=[abs(TLmax) angle(TLmax)*180/pi]	0.7184 103.9397
	Zs2 =
Zs2=(1+Tsmax)*Z0/(1-Tsmax)	6.7593 + 1.1572i
ZL2=(1+TLmax)*Z0/(1-TLmax)	ZL2 =
	12.9934 +37.4412i
F2=Fmin+(4*rn*abs(Tsmax-Tsmin)^2)/((1-	F2 =
abs(Tsmax)^2)*abs(1+Tsmin)^2)	3.7303
Ga2=(abs(S21)^2*(1-abs(Tsmax)^2))/((1-	Ga2 =
abs(Tomax)^2)*abs(1-S11*Tsmax)^2)	13.7451