NYCU RF Design Mid-Term Exam 2023/05/01

1. (10%) In ETSI about receiver characteristics the requirements are given in terms of power levels at the antenna connector of the receiver. Equipment with integral antenna may be taken into account by converting these power level requirements into field strength requirements, assuming a 0 dBi gain antenna. Please verify the fields strengths E(dBuV/m) related to the power levels P (dBm) under 50 ohms impedance by the following formula

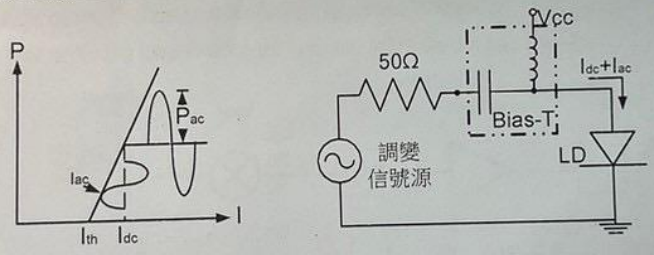
   E (dBuV/m)= P(dBm)+ 20logF(MHz) + 77.2

   Where F is the operating frequency in MHz.

2. (10%) The typical characteristic of output light power P vs. input current I of laser diodes under forward bias is shown in the following figure (a) where I_{th} is the threshold current. This diode can be amplitude-modulated directly from a RF signal source through a bias-T network as shown in figure (b). The Modulation Index m is defined as

$$m = \frac{I_{ac}}{I_{dc} - I_{th}}$$

   Where I_{ac} is the ac current, I_{dc} is the DC bias current. Assume the dynamic resistance equal to 5Ω with I_{th}=20mA and I_{dc}=50mA, find the setting of the RF output power at the front panel to obtain m=80%.



(a) (b)

3. (30%) A load R_L=200Ω is wanted to match the rf source with Rs=50Ω internal impedance. Two methods of wide-band matching are considered. One is to use the transformer, which is lossless and is generally used as a calibrator for insertion loss measurement. The other is to use a resistive network, however with certain loss. Please answer the following questions:

   (a) Find the turn ratio of transformer primary to secondary=1:n for power matching,

   (b) Find the scattering parameters for the transformer with characteristic impedances at input port and output port equal to Rs and R_L, respectively,

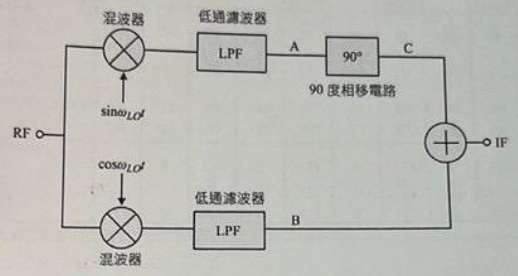
   (c) Verify the insertion loss equal to 0dB

(d) Replace the transformer with a simple two-resistor matching network and find the value of resistors,

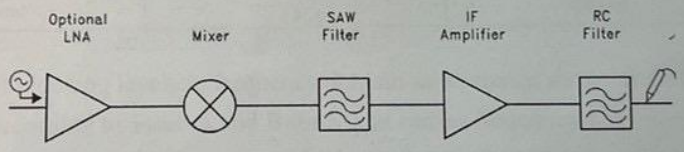
(e) Find the scattering parameters, and

(f) Insertion loss.

4. (10%) The block diagram in the following is the well-known Hartley image rejection mixer. The RF input contains both desired signal and image noise.
RF Signal $= A_{RF}\cos(\omega_{RF}t) + A_{im}\cos(\omega_{im}t)$. *Assume* $\omega_{RF} < \omega_{LO} < \omega_{im}$.
(a) Can you obtain the desired signal at IF port? (b) If not, how to modify the block diagram?



5. (20%) The rf link budget is shown in the figure. The noise figure, gain, and OIP3 in each block are also indicated. Assume input power equal to -93dBm, Find (a) input-referred total NF, (b) total gain, (c) total output power, and (d) total output OIP3.



NF (dB)	3	2	13	20	3	2	10	10	3	2
Gain (dB)	10	10	15	31.6	-3	0.5	20	100	-3	0.5
OIP3 (dBm)	10	10	7.5	5623	100	10^{10}	20	100	100	10^{10}

6. (20%) The frequency bands (I), receiver blocking levels (II), and transmitter spurious (III) for DCS-1800 are listed as follows.

(I) Frequency Band:

- 1710 MHz to 1785 MHz: Up Link;
- 1805 MHz to 1880 MHz: Down Link.

(II) Blocking characteristics

The blocking characteristics of the receiver are specified separately for in-band and out-of-band performance as identified in the following table-A and table-B.

Table-A Frequency Band for blocking signals

Frequency band	Frequency range (MHz) DCS 1 800	
	MS	BTS
in-band	1 785 - 1 920	1 690 - 1 805
out-of-band (a)	0,1 - 1705	0,1 - < 1 690
out-of-band (b)	> 1 705 - < 1 785	N/A
out-of band (c)	> 1 920 - 1 980	N/A
out-of band (d)	> 1 980 - 12,750	> 1 805 - 12,750

GSM-900

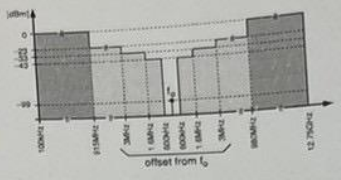


Table-B Blocking Level

Frequency band	GSM 400, P-, E- and R-GSM 900						DCS 1 800 & PCS 1 900			
	other MS		small MS		BTS		MS		BTS	
	dBµV (emf)	dBm	dBµV (emf)	dBm	dBµV (emf)	dBm	dBµV (emf)	dBm	dBµV (emf)	dBm
in-band										
600 kHz ≤ $\|f-f_o\|$ < 800 kHz	75	-38	70	-43	87	-26	70	-43	78	-35
800 kHz ≤ $\|f-f_o\|$ < 1,6 MHz	80	-33	70	-43	97	-16	70	-43	88	-25
1,6 MHz ≤ $\|f-f_o\|$ < 3 MHz	90	-23	80	-33	97	-16	80	-33	88	-25
3 MHz ≤ $\|f-f_o\|$	90	-23	90	-23	100	-13	87	-26	88	-25
out-of-band										
(a)	113	0	113	0	121	8	113	0	113	0
(b)	-	-	-	-	-	-	101	-12	-	-
(c)	-	-	-	-	-	-	101	-12	-	-
(d)	113	0	113	0	121	8	113	0	113	0

NOTE: For definition of small MS, see subclause 1.1.

(III) Transmitter Spurious Emission Measurement 4.3.3.1

Table-C

Band	Frequency offset (offset from carrier)	Measurement bandwidth
relevant transmit band	≥ 1,8 MHz	30 kHz
	≥ 6 MHz	100 kHz

(a) Please plot blocking levels in frequency domain as reference shown from 0.1MHz to 12.750MHz according to Table-A and B for MS at carrier frequency f_o.

(b) Let the receiver sensitivity equal to -99dBm with S/N=9dB and channel BW=200kHz. According to reciprocal effect, please calculate the required phase noise of local oscillator at each offset frequency Δf=0.6MHz, 1.6MHz, 3MHz, and 20MHz, due to blocking effect.

(c) The local oscillator is also used in the transmitter mode. The phase noise is therefore limited by the spurious emission, especially near the band edge. In DCS-1800 the spurious level should be less than -71dBm in the receiver band 1805-1880MHz [3GPP TS-0505 4.3.3.1]. The measurement bandwidth depends on the offset frequency as listed in the Table-C. Please calculate the required phase noise for the transmitter mode at edge 1785MHz with output power +33dBm.

(d) Furthermore, compare and indicate which one between questions (b) and (c) is the most stringent in phase noise under the Leeson model with offset $(\Delta f)^{-2}$ shaping.

1.

由公式 ∵單位輸入功率 $= \frac{E^2}{\eta_0} = \frac{E^2}{120\pi}$

∴ $P_r = \frac{E}{\eta_0} \times \frac{g\lambda^2}{4\pi}$

$= \frac{g\lambda^2 E^2}{480\pi^2} = \frac{gC^2E^2}{480\pi^2 F^2}$

∵ $g = 1 = 0\ dBi$

∴ $P_r\ (mW) = \frac{C^2E^2}{480\pi^2F^2} \times 1000\ (mW)$

$= \frac{(3\times10^8)^2\ E^2(\mu V/m) \times 10^{-12}}{480\pi^2\ F^2_{MHz} \times 10^{12}} \times 10^3$ (10)

$= \frac{1.9\times10^{-8}\ E^2(\mu V/m)}{F^2(MHz)}$

取dB → $E(dB\ \mu V/m) = P_r(dBm) + 20\log F(MHz) + 77.2$

測試天線的設備必須考慮天線場強度，
頻率越大，則天線場強度越大

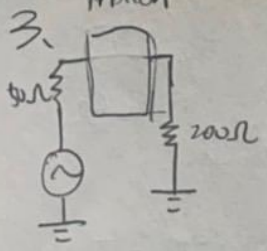
2. 由公式知

$I_{ac} = 0.8 \times (I_{dc} - I_{th}) = 24mA$ ✓

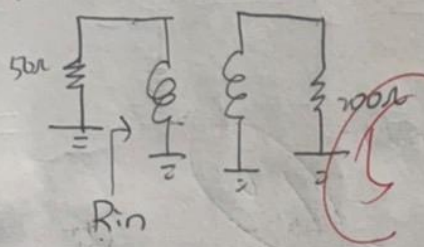
∴ $V_{s,p} = 1.32V$, $V_{rms} = \frac{1.32}{\sqrt{2}}$ (10)

$dBm = 10\log\left[\frac{(1.32/2)^2}{2\times50} / 0.001\right] = 6.39\ (dBm)$ ✓

3. Match



(a) 1 : n



$R_{in} = \frac{200}{n^2} = 50 \quad \therefore n = 2$

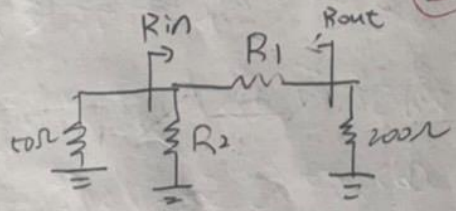
(b)

$S_{11} = S_{22} = 0$

互易 $S_{21} = S_{12} = 1 = \frac{V_2/2}{V_1/2} \frac{V_1/200}{1/50}$

(c) Insertion loss $= 20 \log |S_{21}| = 0\,dB$

(d)



$R_{in} = 50 = R_2 // (R_1 + 200)$

$R_{out} = R_1 + (R_2 // 50)$

$\Rightarrow R_1 = 3R_2$

$R_1 = \frac{100}{53} = 173.2$

$R_2 = \frac{100}{53} = 57.735$

(e)

$S_{11} = \frac{R_{in} - 50}{R_{in} + 50} = 0$ #

($R_{in} = 57.735 // (200 + 173.2) = 50$)

$S_{22} = \frac{R_{out} - 200}{R_{out} + 200} = 0$ #

$R_{out} \doteq 200$

$S_{21} = \frac{b_2/\sqrt{R_L}}{a_1/\sqrt{R_s}} = \frac{V_2/2}{V_1/2} \frac{200}{173.2 + 200} \frac{50}{200}$

$= 0.268$ #

(f) Insertion loss $20 \log |S_{21}|$

$= -11.44\,dB$ #

4.

$$W_{IM} - W_{LO} = W_{LO} - W_{RF}$$

$$RF = A_{RF}\cos W_{RF}t + A_{IM}\cos W_{IM}t$$

$$X_{A(t)} = (A_{RF}\cos W_{RF}t + A_{IM}\cos W_{IM}t)\, A_{LO}\sin W_{LO}t$$

BPF ↓

$$= \frac{A_{RF}A_{LO}}{2}\sin(W_{LO}-W_{RF})t + \frac{A_{IM}A_{LO}}{2}\sin(W_{LO}-W_{IM})t$$

$$= \frac{A_{RF}A_{LO}}{2}\sin(W_{LO}-W_{RF})t - \frac{A_{IM}A_{LO}}{2}\sin(W_{IM}-W_{LO})t$$

經90°相移電路 →

$$-\frac{A_{RF}A_{LO}}{2}\cos(W_{LO}-W_{RF})t + \frac{A_{IM}A_{LO}}{2}\cos(W_{IM}-W_{LO})t$$

$$= X_{c(t)}$$

$$X_{B(t)} = (A_{RF}\cos W_{RF}t + A_{IM}\cos W_{IM}t)\, A_{LO}\cos W_{LO}t$$

$$= \frac{A_{RF}A_{LO}}{2}\cos(W_{RF}+W_{LO})t + \frac{A_{RF}A_{LO}}{2}\cos(W_{RF}-W_{LO})t$$

$$+ \frac{A_{IM}A_{LO}}{2}\cos(W_{IM}+W_{LO})t + \frac{A_{IM}A_{LO}}{2}\cos(W_{IM}-W_{LO})t$$

BPF ⟹

$$\frac{A_{RF}A_{LO}}{2}\cos(W_{RF}-W_{LO})t + \frac{A_{IM}A_{LO}}{2}\cos(W_{IM}-W_{LO})t$$

(a)

$$\text{Signal} = X_{B(t)} + X_{c(t)}$$

$$= A_{IM}A_{LO}\cdot\cos(W_{IM}-W_{LO})t$$

無法得到想要的 RF 訊號

(b) 可將 90° 相移電路由 A 改向 B

5.

(a) 先將dB轉為真值再代公式

$$NF = F_1 + \frac{F_2-1}{G_1} + \frac{F_3-1}{G_1G_2} + \cdots$$

$$= 2 + \frac{20-1}{10} + \frac{2-1}{10\times31.62} + \frac{10-1}{10\times31.62\times0.5} + \frac{2-1}{10\times31.62\times0.5\times100}$$

$$= 3.96 = 5.976\ dB$$

(5)

(b) Total gain

$10+15-3+20-3 = 39\ (dB)$ (5)

(c) $-93+39 = -54\ dBm$ (5)

(d) $$\frac{1}{OIP3} = \frac{1}{OIP3_1 G_2 \cdots G_n} + \frac{1}{OIP3_2 G_3 \cdots G_n} + \cdots$$

$$= \frac{1}{7920} + \frac{2}{281} + 0 + \frac{1}{50} + 0 = 0.0272$$

$$= -15.654\ dBm$$

(5)

$\therefore OIP3 = 15.654\ dBm$

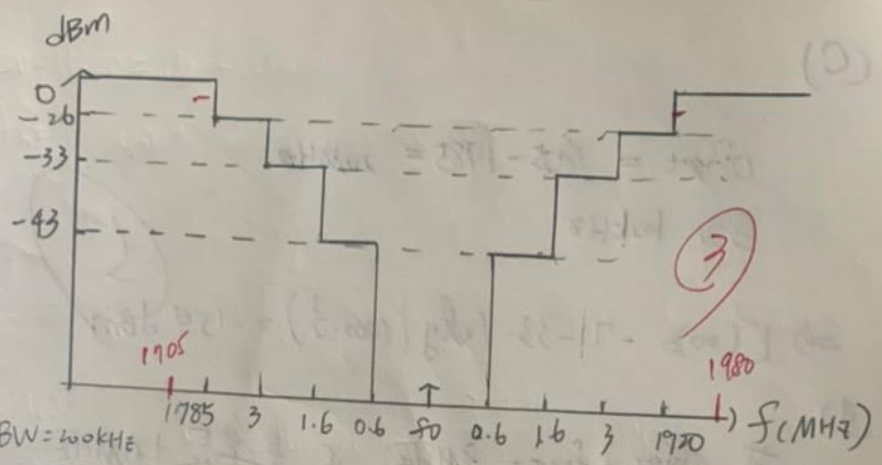
6.

(a)

(b)

6.

(a)



(b) BW = 200kHz

1. offset $\Delta f = 0.6$ MHz

$\Rightarrow L(0.6) = -99 - 9 + 43 - 10\log(200\times10^3) = -18$ dBm

2. $\Delta f = 1.6$ MHz

$\Rightarrow L(1.6) = -99 - 9 + 33 - 10\log(200\times10^3) = -28$ dBm

3. $\Delta f = 3$ MHz

$L(3) = -99 - 9 + 26 - 10\log(200\times10^3) = -35$ dBm

4. $\Delta f = 20$ MHz

$L(20) = -99 - 9 + 12 - 10\log(200\times10^3) = -49$ dBm

(c)

offset = 1805 − 1785 = 20MHz

BW = 100kHz

$\Rightarrow L(20) = -71 - 33 - 10\log(100\times10^3) = -154\ dBm$

(d)

若 offset freq = 3MHz 基準是 1.6MHz

則 phase noise 上升 5.46dB (∵斜率為 20dB/dec)

$-138 + 5.46 = -132.54$

若是 0.6MHz 頻偏的 phase noise 為

$-138 + 14\ dB = -124 \Rightarrow$ 可滿足

若 offset freq = 1.6 MHz

基準 = 3MHz 則 phase noise = −138 − 5.46 = −133.46

基準 = 0.6MHz 則 phase noise = −138 + 8.52 = −115.5

$\Rightarrow$ 無法滿足 3MHz

若 offset freq = 0.6MHz

基準 = 3MHz, 則 phase noise = −118 − 14 = −132

基準 = 1.6MHz, 則 phase noise = −118 − 8.52 = −126.5

$\Rightarrow$ 皆無法滿足

∴ 整體來說，3MHz 頻偏的要求最嚴格