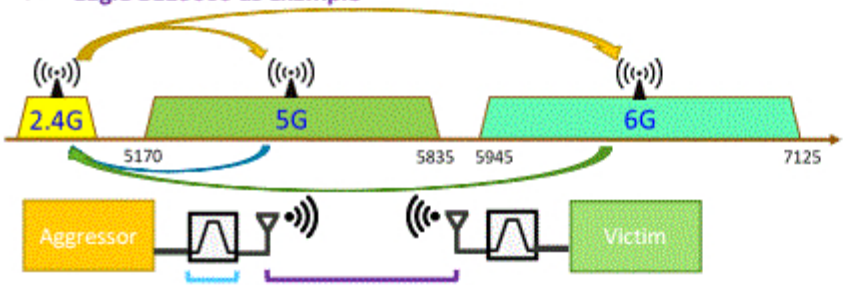
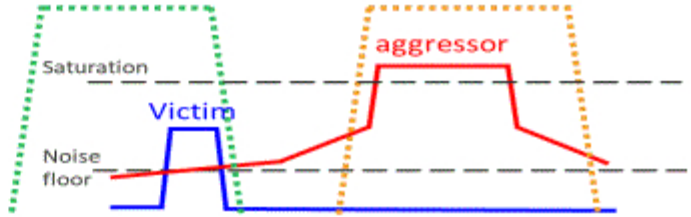
[Eagle] Antenna Design Guide (cross-band isolation)

➢ **Eagle BE19000 as example**



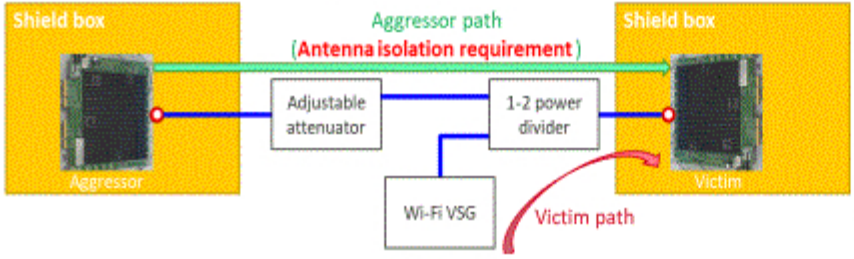
Total rejection ≒ agg. filter rejection + antenna isolation



① Aggressor TX saturate victim band RX LNA

✓ ② Aggressor out-band emission de-sense victim band RX

➢ **Minimum antenna isolation for MLO**



2GHz band discrete LPF, Rejection > 30dB @ 5/6GHz band
5GHz band DR filter - SY01154821Y91B410 (5150~5835MHz), Rejection > 46dB @ 6GHz band
6GHz band DR filter - SY01165251J91D410 (5950~7125MHz), Rejection > 47dB @ 5GHz band

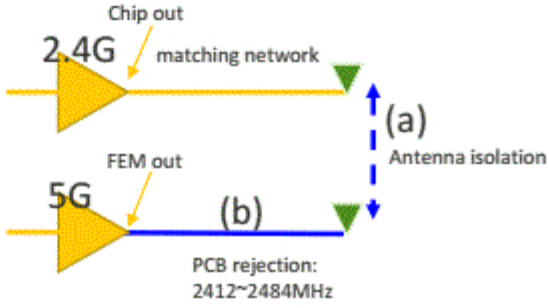
Test case		De-sense			
Victim	Aggressor	0.5	1.0	2.0	3.0
2.4G	5G	15	15	15	15
	6G	20	20	15	15
5G	2.4G	15	15	15	15
	6G	35	35	30	30
6G	2.4G	15	15	15	15
	5G	25	20	15	15

Isolation(dB)

Eagle BE19000 cross-band isolation

[Griffin] BE7200 2i5e EN55032 EMI Application Note

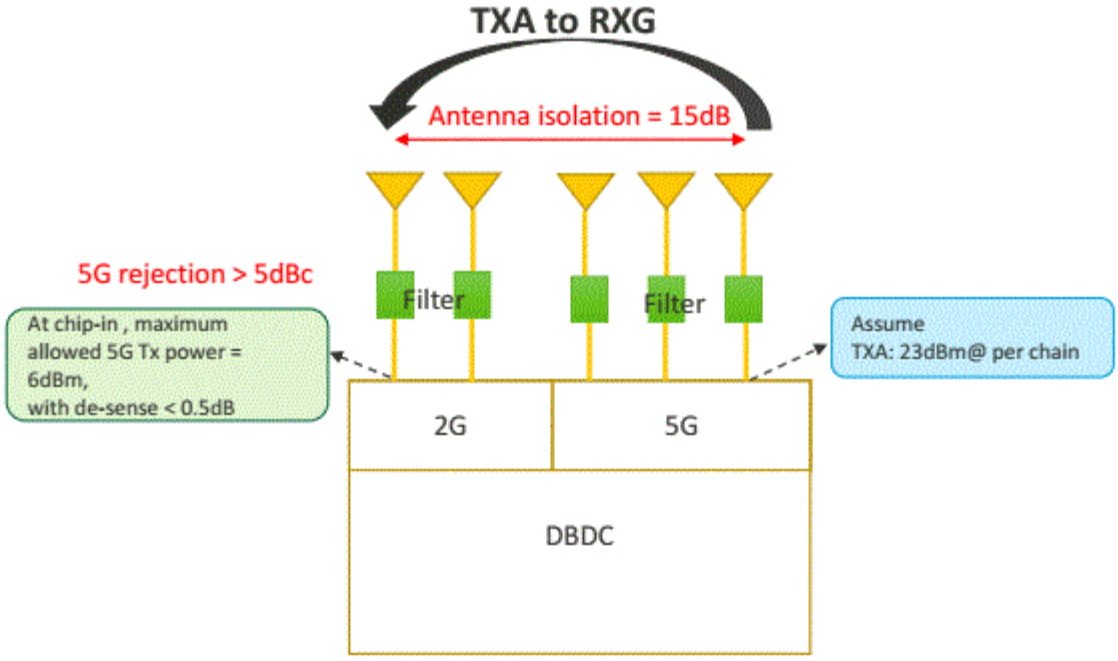
- **For 2.4GHz and 5GHz band isolation, PCB +Antenna isolation: (a)+(b) must >20dB**
- **If (b) is 0dB rejection, (a) antenna isolation must >20dB, external diploe or antenna distance >8cm.**
- **If (a) antenna isolation <20dB, (b) need to improve PCB rejection, ex: PCB matching design notch filter, BPF or diplexer in 5G RF path.**



Kite BE7200 2i5e EN55032 Application Note

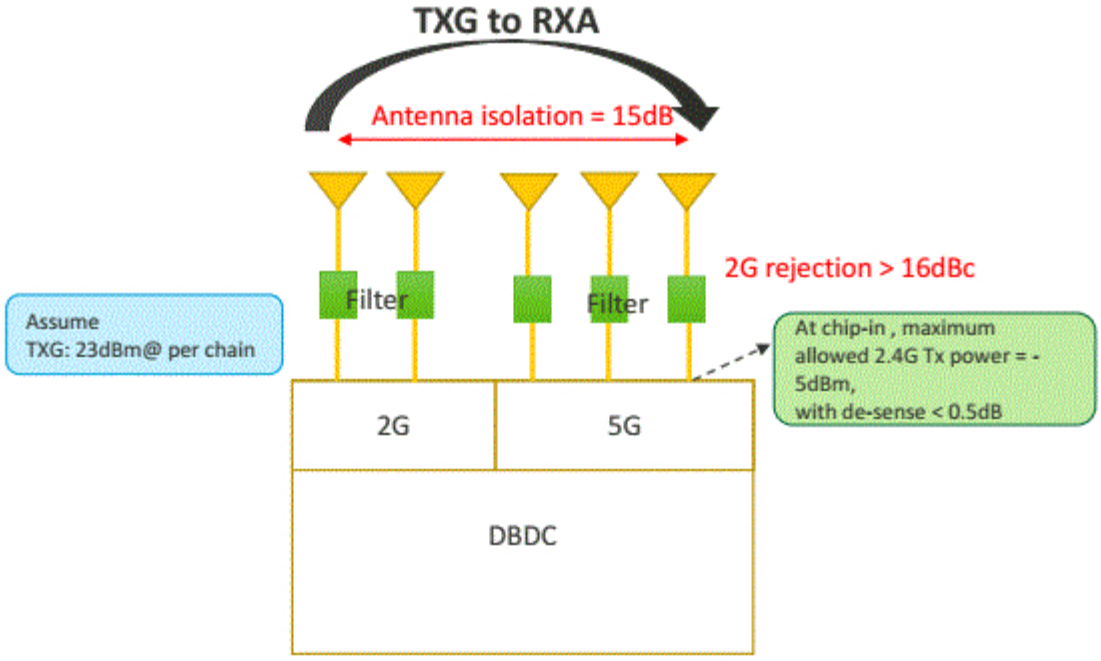
DBDC Cross-Band Rejection

➢Assume the antenna isolation of cross-band is 15dB, the out-band rejection of 2.4G-port needs to be 5dBc more in 5GHz band. (Assume Antenna gain =0 & without BF)



DBDC Cross-Band Rejection

➢Assume the antenna isolation of cross-band is 15dB , the out-band rejection of 5G-port needs to be 16dBc more in 2.4GHz band . (Assume Antenna gain =0 & without BF)



[DBDC] Maximum Allowed Cross-band Interference Power at chip-in

To make de-sense as less as possible ,

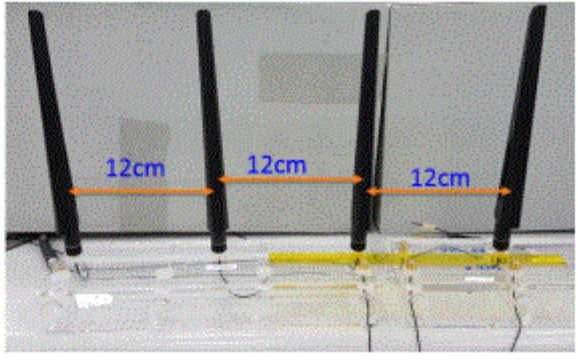
- **At 5GHz RX port,**
  - Maximum allowed input 2.4GHz power <-5dBm , with de-sense < 0.5dB
- **At 2.4GHz RX port,**
  - Maximum allowed input 5G Tx power < 6dBm , with de-sense<0.5dB
- **Out-band rejection depends on the TX power of out-band .**
  - The more TX power of out-band is , The higher out-band rejection is .
    - Out-band rejection : [the band rejection of filter] + [cross-band antenna isolation]

Merlin BE5000 DBDC Out-band Rejection study

[Reference] 12 cm Separations(2.4 GHz Band)

	Whayu 2dBi	Masterwave 4dBi	AC87 4dBi
S01	25	25	22-24
S02	31	29.8	28.5
S03	36	35	27.5
S12	27	36	23.7
S13	33	31	27
S23	28	27	23.5

Vertical dipole
Isolation >25dB



[Reference] 8cm Separations (2.4 GHz Band)

	Vertical dipole			Slant dipole		
	Whayu 2dBi	Masterwave 4dBi	AC87 4dBi	Whayu 2dBi– 傾斜 20,45	Masterwave 4dBi – 傾斜 20,45	AC87 4dBi– 傾斜 20,45
S01	18	19	17	22.7	23	22.8
S02	26.9	25	24	31	29	56
S03	24.8	27	25.4	35	31.5	52.5
S12	19.1	21.9	17.9	22.5	28	30
S13	24.7	24.3	26	29	30	38
S23	19	17.3	16.7	22.5	23	23.6

[Vertical dipole ,8cm distance]
2.4GHz Band:
1-2 dB sensitivity loss

[Reference] 8cm Separations (5 GHz Band)

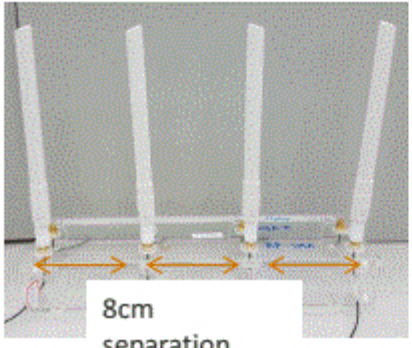
	Whayu 2dBi	Masterwave 4dBi	AC87 4dBi	Whayu 2dBi– 傾斜 22,45	Masterwave 4dBi – 傾斜 22,45	AC87 4dBi– 傾斜 22,45
S01	27	27	26.7	29	46	26.7
S02	40	34	30	37	42	49
S03	34	40	35	49	49.5	51.7
S12	27	28	27	32	30	40
S13	34	34	32	39	40	45
S23	28	27	27	30.8	28	33

Isolations of 5GHz band is good .

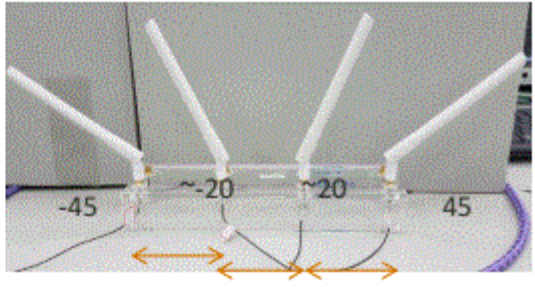
[Griffin] Antenna isolation study

根據天線的隔離度測試, 建議間距 :
1. 天線直立(vertical)排成一直線,間距8cm , 5GHz band天線隔離度已足夠 (>25dB) .
2. 對2.4GHz band而言,間距12cm以上隔離度可以大於25dB .

Vertical , (0 degree)



20,45 degree tilted



Antenna isolation study with different antenna gain and polarization

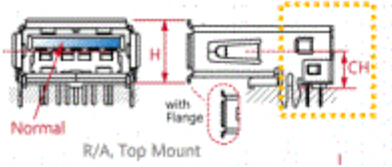
Appendix

OTA (Over The Air) Performance Check

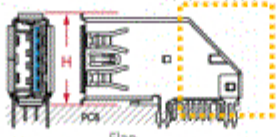
Items	Description	Check	Check
1	Antenna in-band return loss (Must consider with housing and mechanism.)	<-10dB (Lower is better)	
2	Measure conductive mode performance as baseline.	a. TX power/EVM b. RX sensitivity c. Conducted RvR	
3	OTA performance comparison	a. EVM degrade < 3dB b. Sensitivity degrade < 3dB c. if OTA RvR meet spec.	

USB3.0 Connector Type

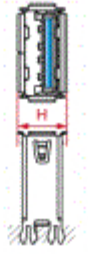
- **USB connector**



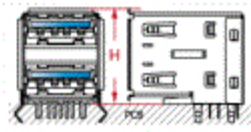
R/A, Top Mount



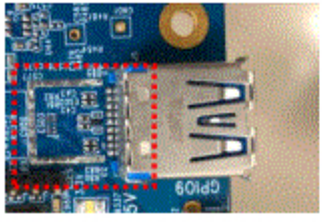
Flag



Vertical



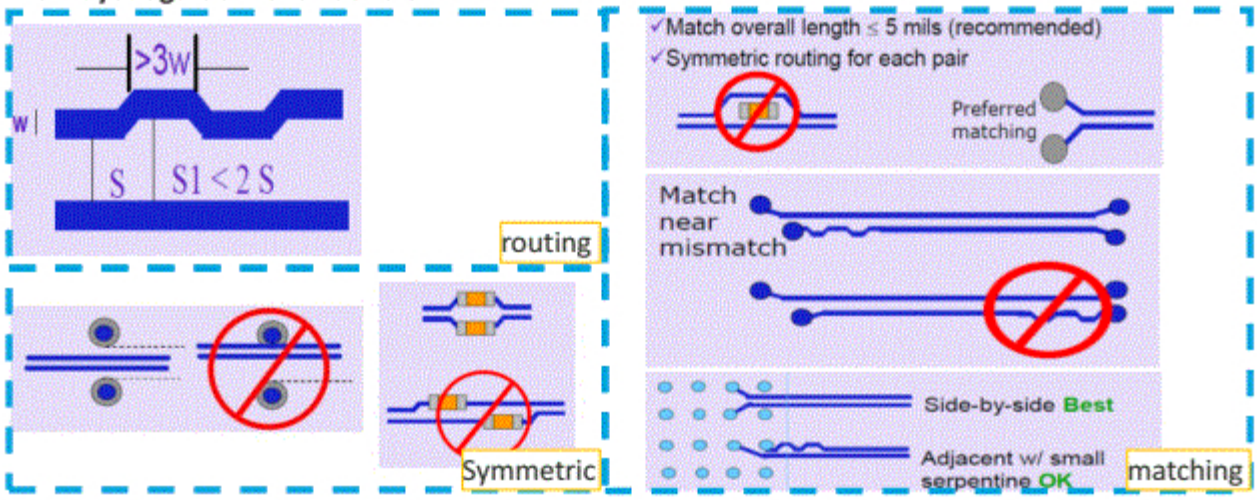
Stack



- USB3.0 connector need shielding for pin header.
- Add shielding can for USB trace component.
- Use two port USB connector.

USB3.0 Layout Guide

PCB layout guideline for USB3.0

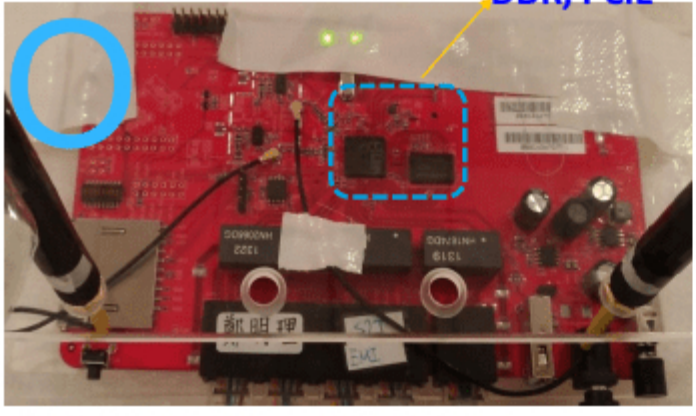


- The PCB layout guide for USB3.0 differential lines.
- Symmetric routing for USB3.0 trace.
- U3 trace layout in inner layer.

[Griffin] Antenna Cable Routing (IV)

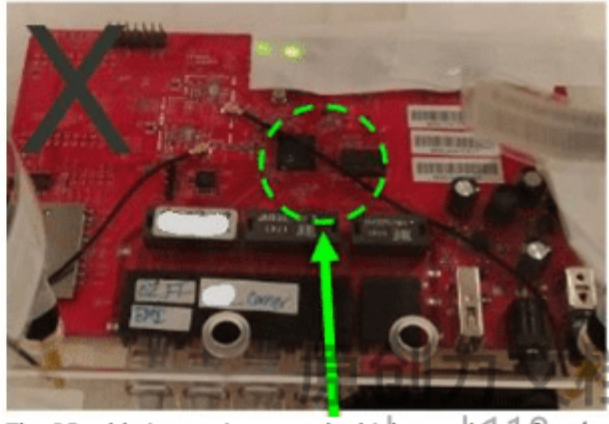
- Do not route RF cable crossing over the high speed traces and noise source ,like BT&Wifi , HDMI, USB3.0, DDR , or PCIE .
  - To avoid interference signal is induced and radiated by the antenna .
  - To avoid the RF signal interfering the high speed signals .

Good



RF cables are not crossing over the high speed interface/trace and RF chips .

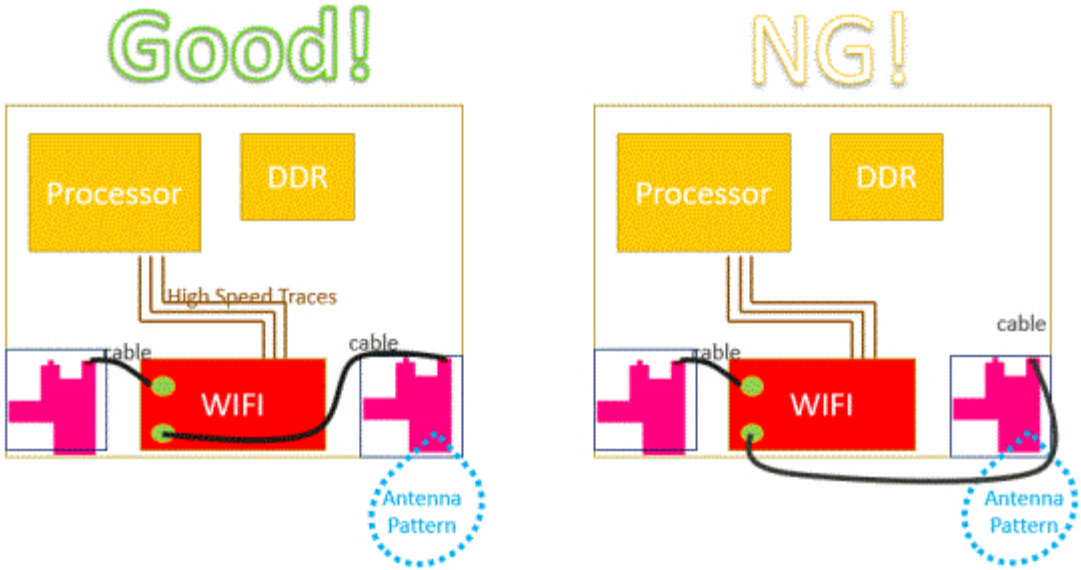
Not good



The RF cable is crossing over the high speed interface/trace and RF chips .

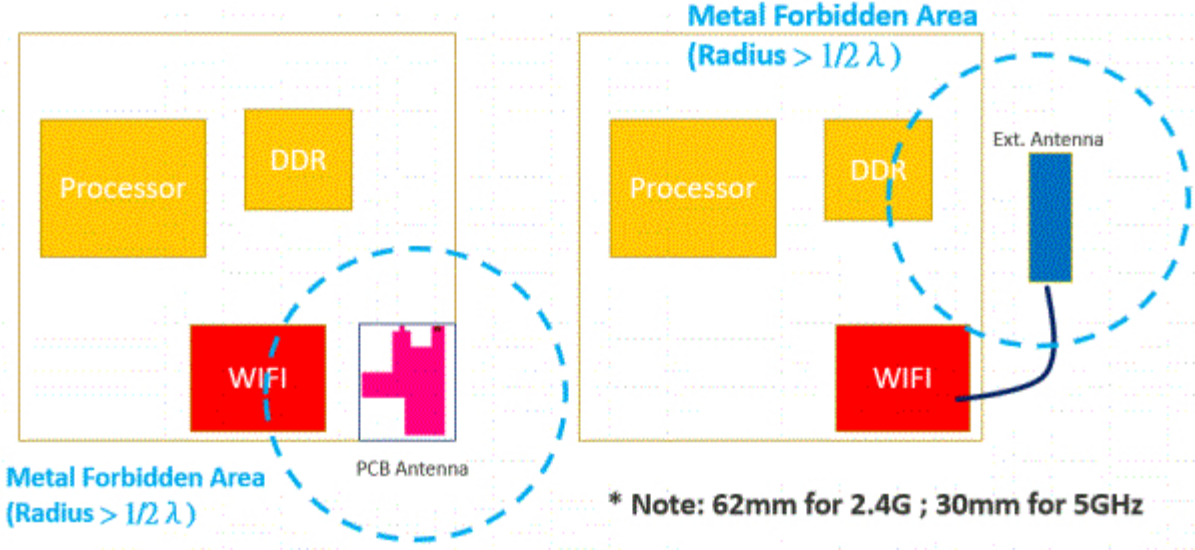
[Griffin] Antenna Cable Routing (III)

- **Do not route RF cable around the embedded antenna and interfere the radiated pattern of antenna.**



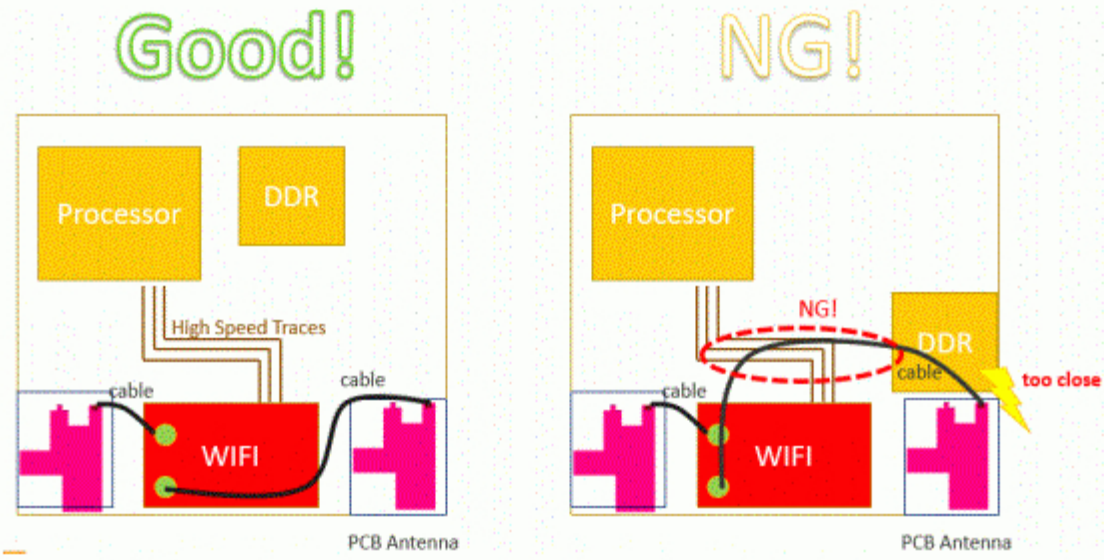
[Griffin] Antenna Cable Routing (II)

- **Keep antennas away from metal components as far as possible, like the metal plate and metal case.**



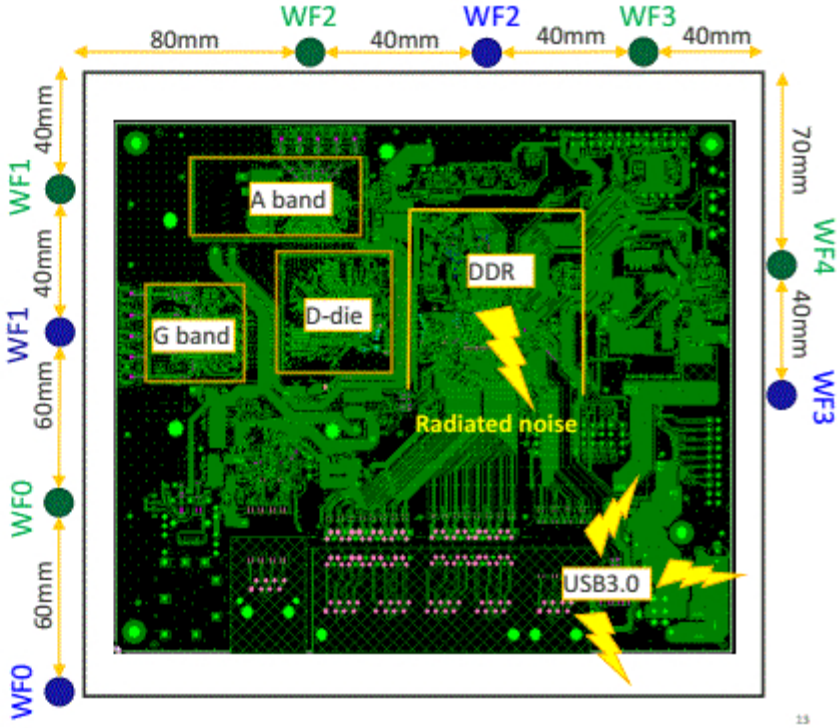
[Griffin] Antenna Cable Routing (I)

- **Keep antennas and the RF cable away from noise source. Do not route RF cable crossing over the high speed traces. (DDR, HDMI, USB 3.0, SATA)**

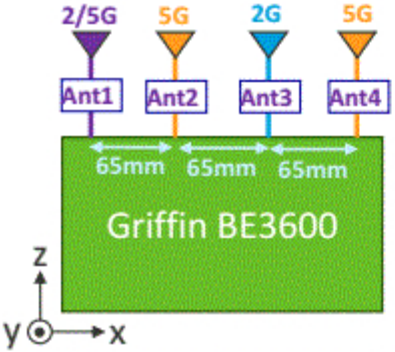


[Griffin] Antenna Placement (BE7200)

- For 2.4GHz band, >25dB antenna isolation can be obtained with **12cm** placed distance.
- For 5GHz band, >25dB antenna isolation can be obtained with **8cm** placed distance.
- Antenna placement need to far away DDR and USB3.0.



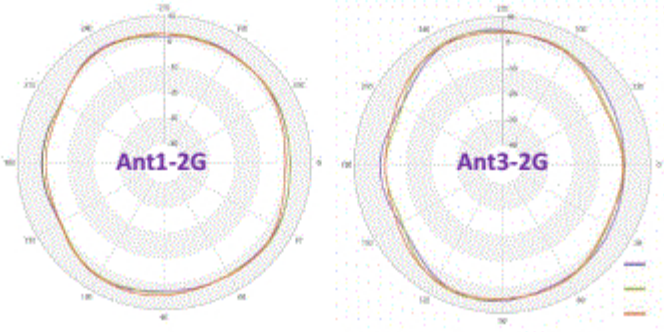
[Griffin] Antenna Placement (BE3600, Solution(b))



Antenna design by LYNwave

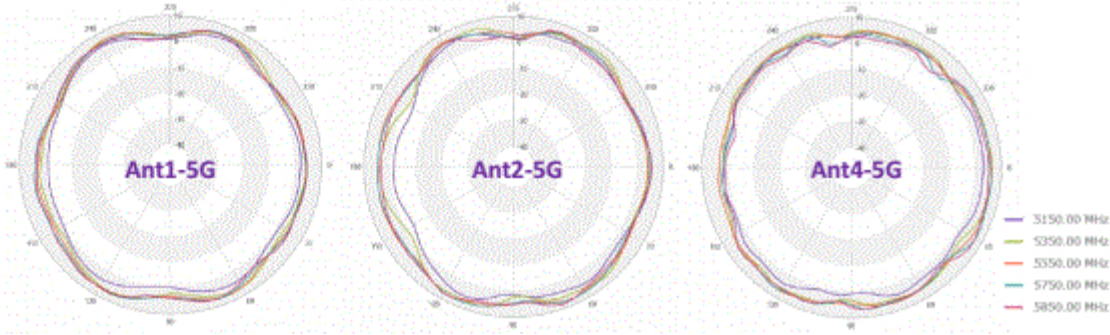
	P/N
Ant1	ALX24P-221AAB-A
Ant2	ALX24P-091AA2-00
Ant3	ALX24P-051AA1-00
Ant4	ALX24P-091AA2-01

Contact window:
Brian Hung brianhung@lynwave.com

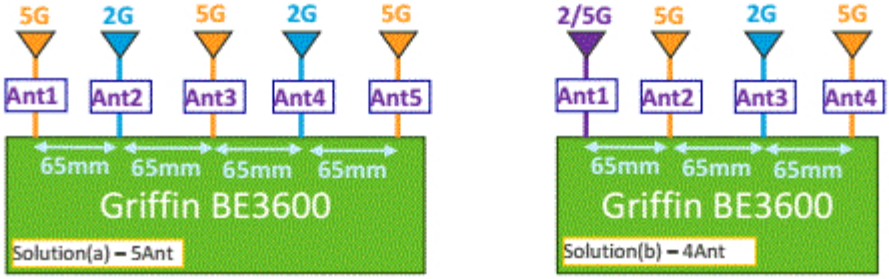


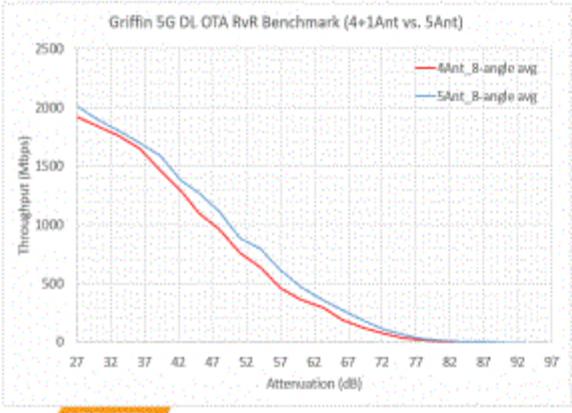
	WIFI
Return Loss – 2G	< -10dB
Return Loss – 5G	< -10dB
Isolation – 2G	< -20dB
Isolation – 5G	< -20dB
Efficiency – 2G	> 68%
Efficiency – 5G	> 72%
Peak Gain – 2G	4.0~4.5dBi
Peak Gain – 5G	

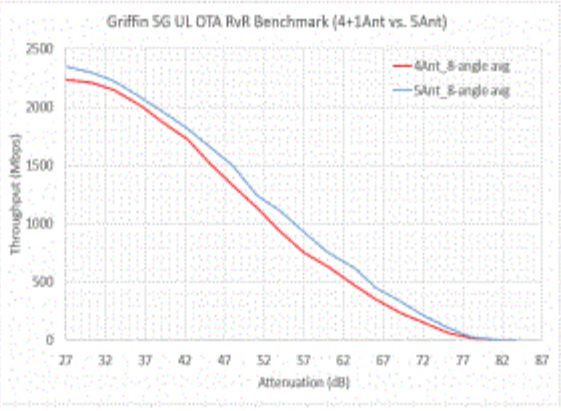
Meet 2x2MIMO requirement



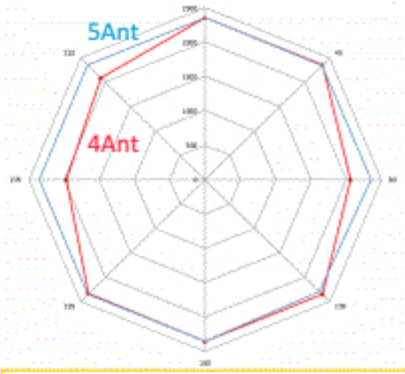
[Griffin] Antenna Placement (BE3600, 5Ant vs. 4Ant)







Throughput v.s Angle Measurement



Due to antenna coverage, the 8-angle average RvR of 5Ant is better than 4Ant.

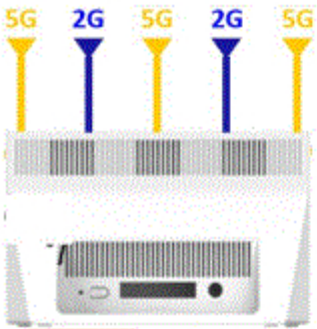
[Griffin] Antenna Placement (BE3600)

內部評估的性價比如下
特性: (a) > (d) ~(b) > (c)
Cost: (c) > (d) ~ (b) > (a)
建議favor特性 選(a)
如果favor cost 選(c) , 但是建議(d) 在PCB預留co-layout.

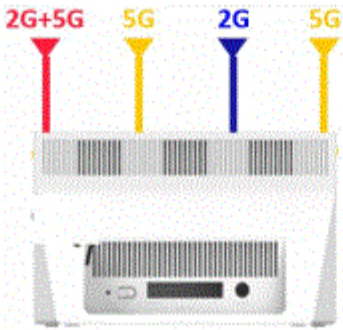
- Performance: antenna type 2 > 3 > 8
- Cost: antenna type 8 < 3 < 2

Antenna type	Antenna	Diplexer ($0.05 USD)	eFEM (n=$0.2 nb=$0.4)	Cost delta
5 antenna (MTK) 2	4: 0.18 x 2 5: 0.17 x 3	N/A	N/A	Baseline: 0
4 antenna (MTK) 3	3: 0.18 x 1 4: 0.18 x 1 5: 0.17 x 2	0.05x1=0.05	N/A	-0.12
4+1 antenna (MTK) 8	4: 0.18 x 2 5: 0.17 x 2	N/A	N/A	-0.17

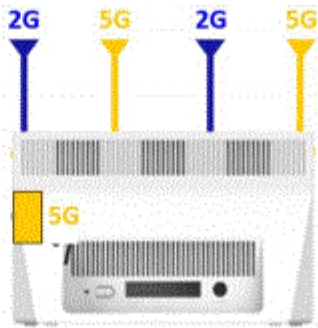
Solution (a)



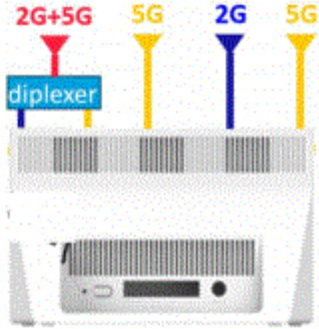
Solution (b)



Solution (c)

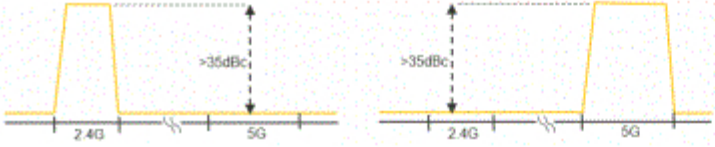


Solution (d)



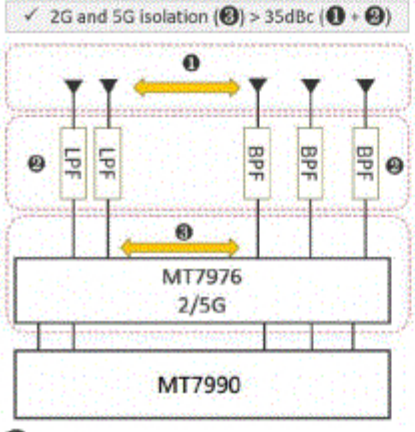
[Griffin] Antenna Design Guide (cross-band isolation)

Cross-band isolation requirement



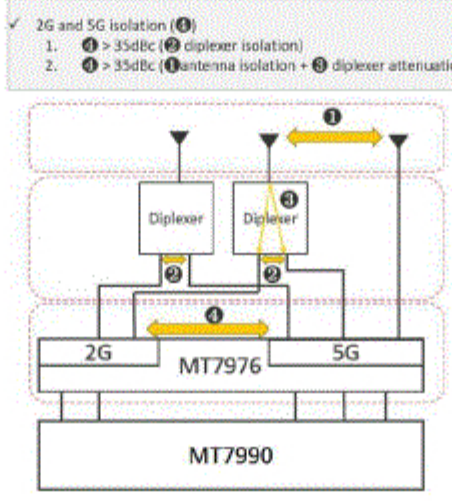
2G and 5G isolation must be **>35dBc** for DBDC and MLO to avoid performance degradation when one band is TX and the other band is RX.

Case1 (single-band antennas)

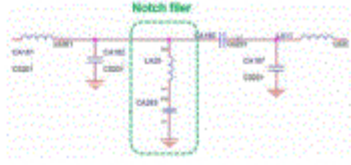


isolation (❶)
and BPF isolation (

Case2 (2/5G dual-band antennas + 5G single-band antenna)



A. For 2/5G dual-band antenna, isolation is dominated by the diplexer((❷) must be >35dBc). If the diplexer isolation can't meet >35dBc, RF path can add a notch filter to increase rejection.



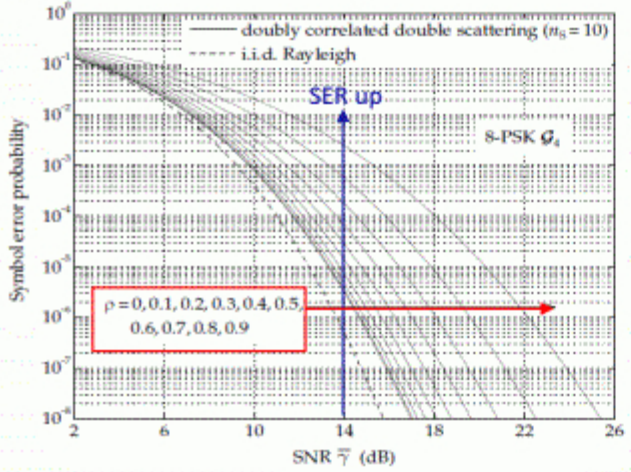
B. For 2/5G dual-band and 5G single-band antenna, total isolation (❹) includes antenna isolation (❶) and diplexer attenuation (❸).

[Griffin] Antenna Design Guide (co-band isolation)

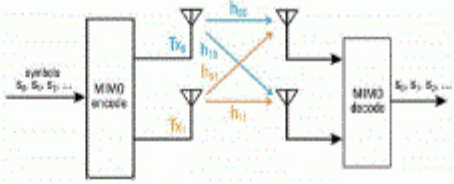
Correlation coefficient and SER

$$\rho_e = \frac{\left|\iint_{4\pi} d\Omega F_1(\theta,\phi)\cdot F_2(\theta,\phi)\right|^2}{\iint_{4\pi} d\Omega\left|F_1(\theta,\phi)\right|^2 \iint_{4\pi} d\Omega\left|F_2(\theta,\phi)\right|^2} = \frac{\left|\sum_{n=1}^{N} S_{i,n}^{*} S_{n,j}\right|^2}{\prod_{k=(i,j)}\left[1-\sum_{n=1}^{N} S_{i,n}^{*} S_{n,k}\right]}$$

兩天線輻射場型內積看相似度　發射與接收功率一樣才成立



MIMO throughput considered antenna parameter and channel model



Shannon theory with channel model (fading)

$$C = \log_2|I + SNR \cdot HH^H|$$

Consider antenna parameter

$$C = \log_2|I + SNR \cdot EFF \cdot \rho_c \cdot HH^H|$$

$$\rho_e = |\rho_c|^2$$

Throughput (theory) = C * BW (bps)

Throughput = BW subcarrier * modulation bits * coding rate * duration * (1-PER)

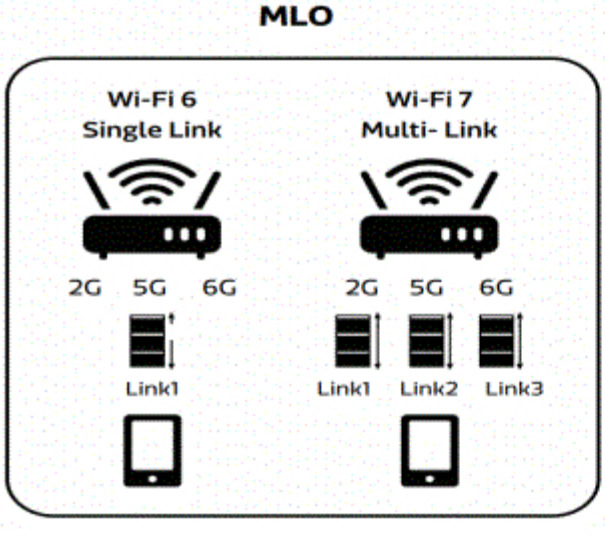
|ρ| (Ant. Corr.)	Capacity Degrade (2x2 MIMO)	Capacity Degrade (4x4 MIMO)
0.1	0%	1%
0.2	3%	8%
0.3	6%	23%
0.5	13%	
0.7	28%	

MCS13	BW40	BW160
2x2	20	20
3x3	22	24
4x4	24	26
4x5		24

MIMO Antenna Isolation for Fading Channel (TGnBNL), Sensitivity Loss < 1.0dB

Y. A. S. Dama, A. S. Hussaini, R. A. Abd-Alhameed, S. M. R. Jones, N. J. McEwan, T. Sadeghpour, and J. Rodriguez, "Envelope Correlation Formula For (N,N) MIMO Antenna Array Including Power Losses," *2011 18th IEEE International Conference on Electronics, Circuits, and Systems, 2011.*

[Griffin] Antenna Design Guide (MLO Introduction)

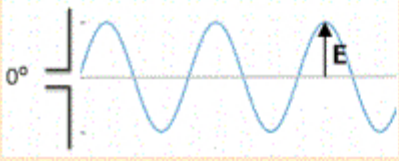
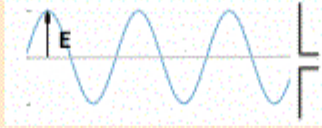
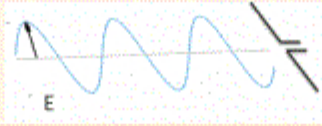


To keep good RvR with MLO, co-band and cross-band **isolation** of antennas are needed to enhance channel capacity (spectrum efficiency).

Kite sku	2G	5G	6G
BE7200	4T4R, 4ss	5T5R, 4ss	
BE7200	4T4R, 4ss		5T5R, 4ss
BE6500	3T3R, 3ss	5T5R, 4ss	
BE5040	2T2R, 2ss	3T3R, 4ss	

[Griffin] Antenna Design Guide (Polarization Loss)

Measured with 2 dBi dipole

TX ANT polarization	RX ANT polarization		Polarization Loss (dB)
		0° , Parallel	0dB (pol. match)
		45° slant	~ 3 dB
		90°, Orthogonal	8dB ~ 10 dB loss (pol. mismatch)

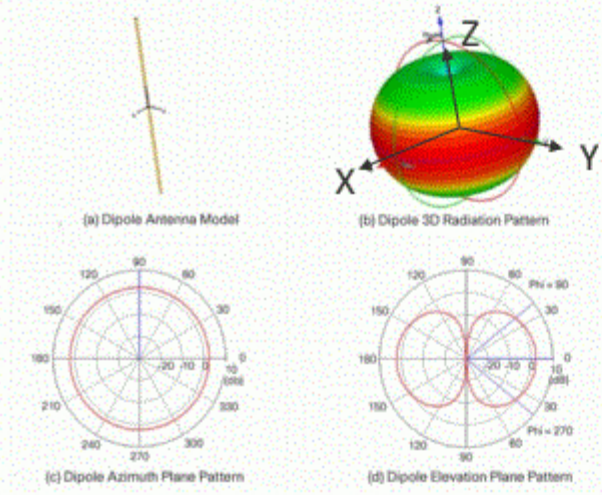
(Especially in 5GHz band) Due to AP antennas' polarization is vertical in general , we suggest client's antenna polarization to be more the same with AP's .

1. For flat-lying BOX : external dipole > pifa designed with vertical pol. > printed on board .
2. For vertical stand BOX : external dipole > Printed or pifa

(Depending on the vertical gain and the radiation pattern ,Omni-ly is better.)

[Griffin] Antenna Design Guide (Radiation pattern)

Figure 4. Dipole Antenna with 3D Radiation Pattern, Azimuth Plane Pattern and Elevation Plane Pattern



http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-antennas-accessories/prod_white_paper0900aecd806a1a3e.html

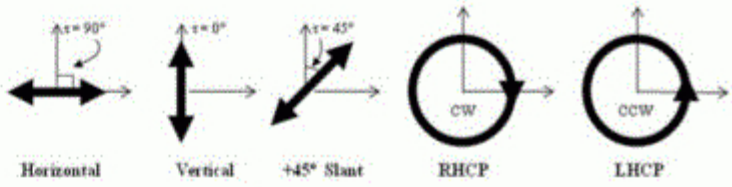


Figure 10 : Classification of the different polarizations with respect to type and sense.

http://www.mtiwe.com/?CategoryID=353&ArticleID=163

- Radiation Pattern: **Omni-directional in horizontal plane**
- Polarization (E field): **Vertical polarization (dipole)**

[Griffin] Antenna Design Guide

- MIMO Antenna Isolation for Fading Channel (TGnBNL), Sensitivity Loss < 1.0dB

MCS13	BW40	BW160
2x2	20	20
3x3	22	24
4x4	24	26
4x5		24

- 2.4GHz & 5GHz isolation ≥ 35 dB (Antenna isolation + Filter / Diplexer Rejection)
- VSWR < 2 in 2.4&5 GHz band
- Antenna Gain > 1dBi (depends on customer's spec)
- Antenna Efficiency > 50%
- Radiation Pattern: Omni-directional in horizontal plane
- Polarization (E field): Vertical polarization (dipole)

Contents

Revision History

Revision	Date	Author	Description
V1.0	2024/8/6	Teddy	Initial version
V1.1	2024/12/2	Teddy	1. Add cross-band isolation requirement in detail. 2. Add BE3600 antenna reference design for 4Ant case. 3. Griffin BE3600 RvR benchmark for 5Ant and 4Ant.

Griffin Antenna Application Note

ICB/RSD/RF3

Teddy