Oct. 2024

可重構智慧表面(RIS)OTA量測

-邱宗文 博士 (川升股份有限公司 創辦人)

講者介紹

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台北工專電機科
中山大學電機博士

經歷

- 第四屆臺灣天線工程師學會理事長
- 成功/逢甲/台北大學等兼任助理教授
- 資深科大/技術學院評鑑委員
- 連展無線通訊事業處處長
- 川升股份有限公司創辦人&現任總經理
- 至高頻科技/正于微波共同創辦人
- 2022低軌衛星工業局科專計畫負責人
- 2022國家發明獎/經濟部創新研究獎獲獎人
- 約200項發明專利發明人
- 川升學苑創辦人

專長

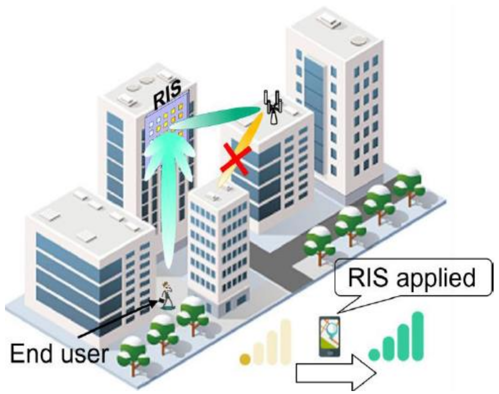
- 天線OTA量測、天線設計及微波電路應用

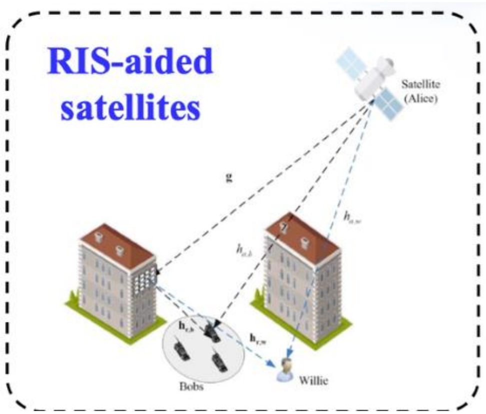
大綱

- **RIS及OTA量測重要參數介紹**
- RIS OTA量測文獻分享
- RIS OTA量測系統介紹
- 結論

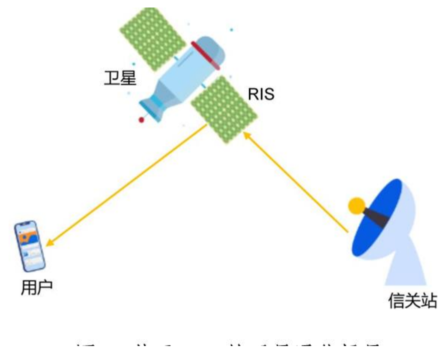
Why RIS?

- 5G sub6/mmWave
  - Blockages
  - Severe path loss
  - Channel capacity
- Satellite/UAV
  - Transponder
  - Enhance Aperture size
  - Stealth
- RIS (Reconfigurable Intelligent Surfaces)
  - Cost-effective
  - Power-efficient





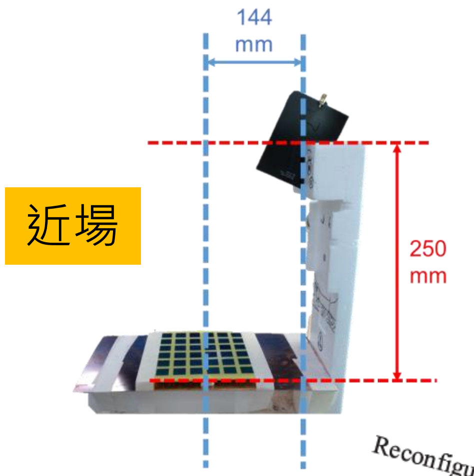
增強收訊/匿蹤

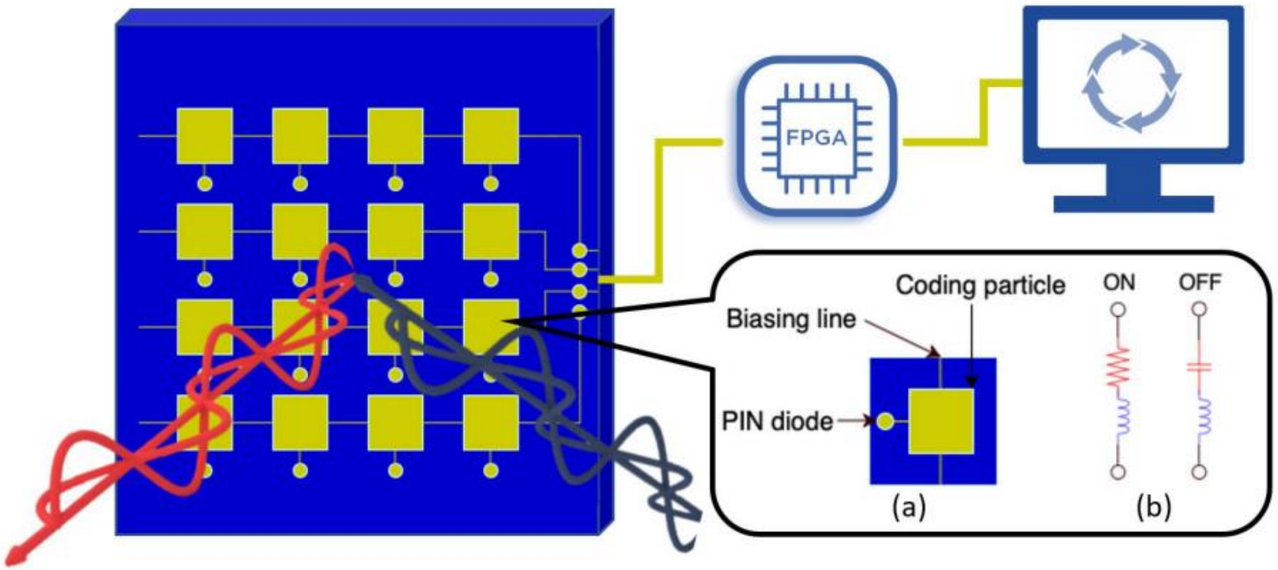


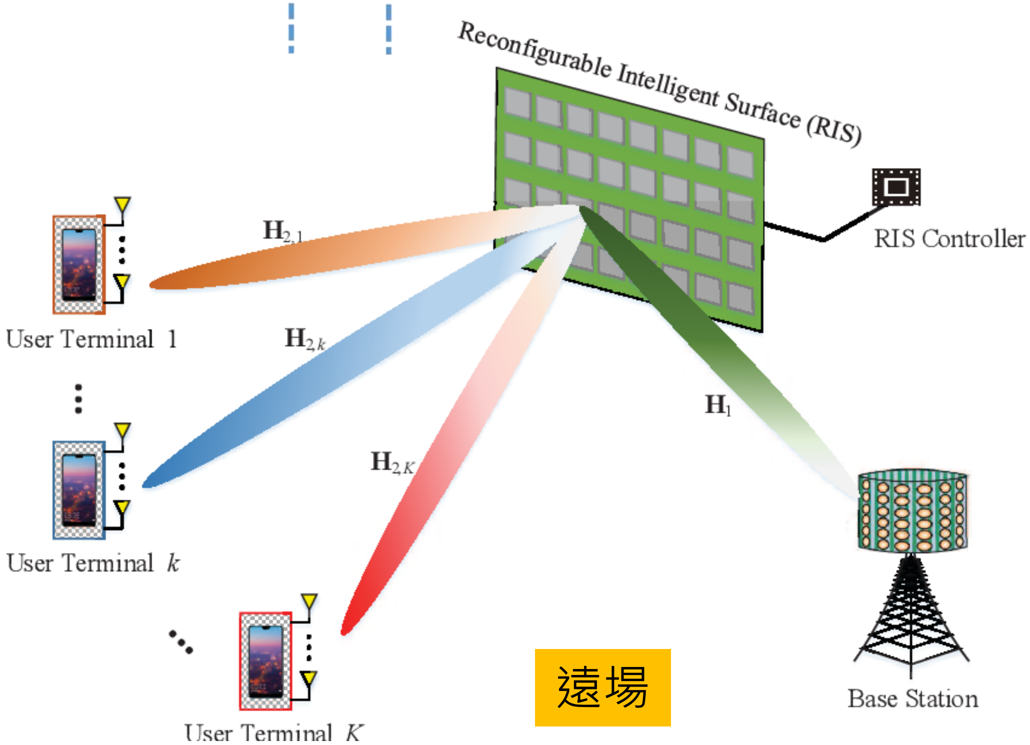
資料來源：網路

What is RIS?

- Planar surface structure (NF & FF)
- Changing the directions of reflected/transmited signal
- Reconfiguring the wireless propagation environment





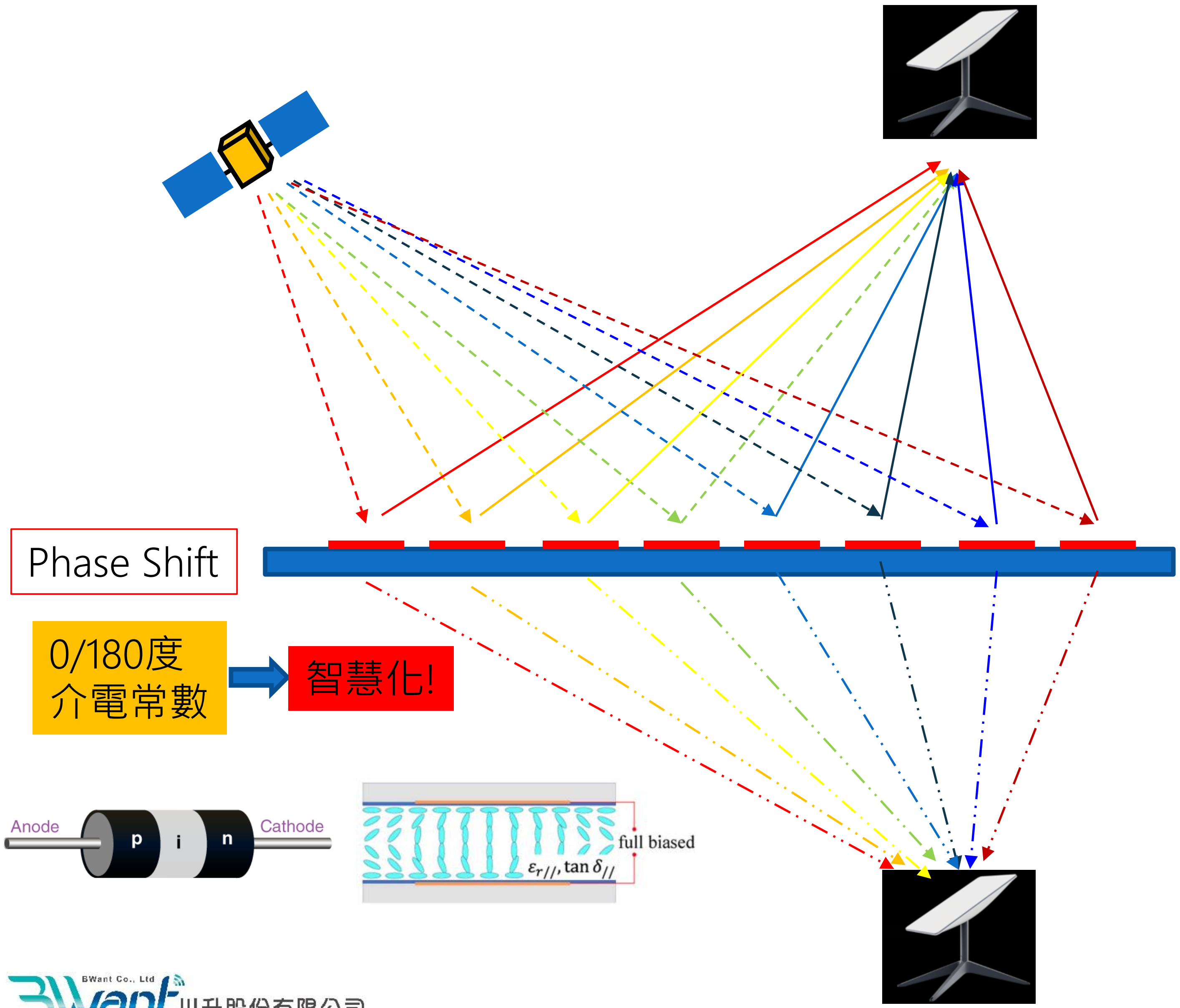


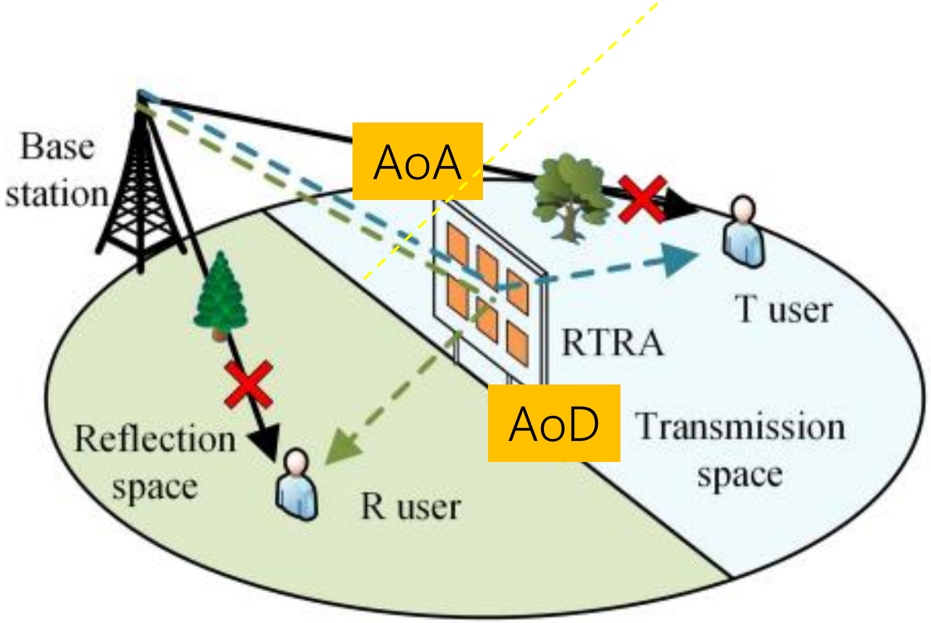
L. You *et al*., "Reconfigurable Intelligent Surfaces-Assisted Multiuser MIMO Uplink Transmission With Partial CSI," in *IEEE Transactions on Wireless Communications*, vol. 20, no. 9, pp. 5613-5627, Sept. 2021

C. Pan *et al*., "Reconfigurable Intelligent Surfaces for 6G Systems: Principles, Applications, and Research Directions," in *IEEE Communications Magazine*, vol. 59, no. 6, pp. 14-20, June 2021

https://xsj.699pic.com/pay/index?click_type=851

RIS設計原理





Phase Shift

0/180度
介電常數 → 智慧化!

反射： Phase (------) + Phase (——) + Phase Shift

穿透： Phase (------) + Phase (-·-·-) + Phase Shift

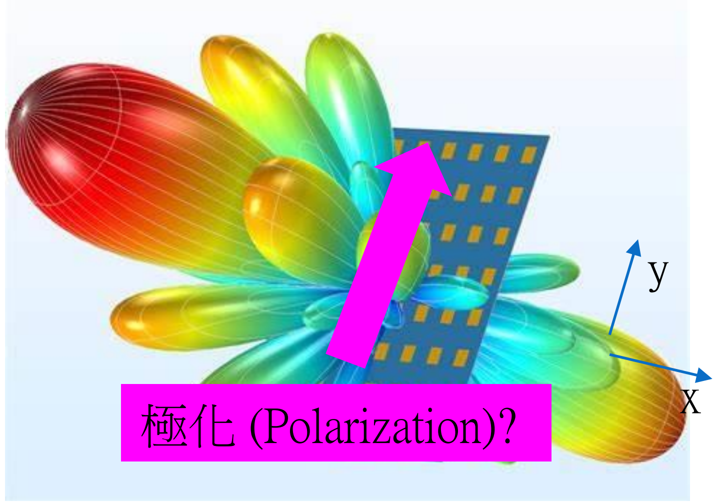
↓

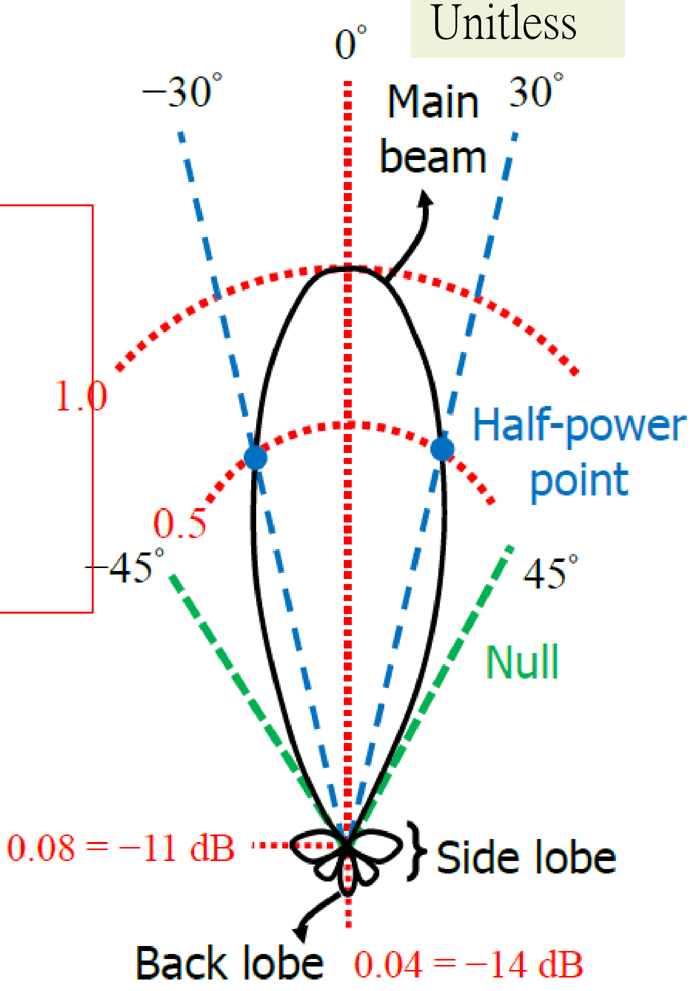
相等!

重要參數-輻射場型

E-plane/H-plane
Co. pol./X-pol

Directivity : peak/aver.
HPBW (Half power beamwidth)
SLL (side lobe level)
F/B (front to back ratio)
XPL (cross pol. Level)





Monostatic/Bistatic!

Terminologies concerned about the pattern:

Antenna boresight	The direction of maximum radiation
Half-power beam width (HPBW)	The angle between the half-power point (AKA 3 dB beam width)
Beam width between first nulls (FNBW)	The angle between first nulls for main beam
Front-to-back ratio (F/B ratio)	The ratio of power gain between the front and rear of a directional antenna
Side lobe level (SLL)	The power level of the peak of the side lobe (expressed in decibels)

OTA SNR!!!

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重要參數- Aperture Efficiency

Gain

Wavelength

$$A_{\text{eff}} = \frac{G\lambda^2}{4\pi}$$

Effective Aperture

$$e_a = \frac{A_{\text{eff}}}{A_{\text{phys}}}$$

Aperture Efficiency

天線尺寸

- 2.4 GHz
- 24 inch diameter (0.2235 square meters area)
- 21 dBi

$$e_a = \frac{10^{21\text{dBi}/10}\ c^2}{4\pi\ 0.2235\ \text{m}^2\ (2.4\ \text{GHz})^2} = 70\%$$

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 63, NO. 11, NOVEMBER 2015

Design of a Wideband Dual-Polarization Full-Corporate Waveguide Feed Antenna Array

Shi-Gang Zhou, Guan-Long Huang, Tan-Huat Chio, Jiang-Jun Yang, and Gao Wei

Moreover, the aperture efficiency is estimated by

$$\eta_{AE} = \frac{G\lambda_0^2}{4\pi\ A} \times 100\% \qquad (1)$$

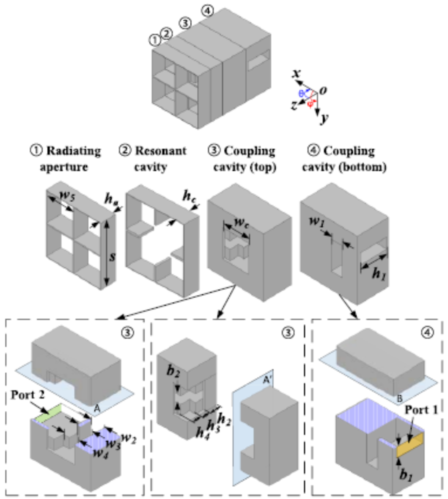

Fig. 2. Configuration of the 2 × 2-element subarray.

Feed Networks	Volume Size (λ_L^3)	Central Frequency (GHz)	Impedance & AR Bandwidth (GHz)	Peak Gain (dBic)	Aperture Efficiency
Conventional	2.9×1.8×0.6	8.25	8.15-8.35	16.1	62.5%
		14.5	14.2-14.8	15.2	16.4%
Conventional, PRGW lines	2.3×1.7×0.3	20	19.4-20.4	13.2	59.4%
		30	29.5-30.9	11.5	18.8%
CP horn	14.2×14.2×0.6	12.5	12.2-14.1*	25.3	13.8%
		30	27.3-31.6*	31	15.6%
Sequential rotation	2.5×2.5×0.08	7.55	7.4-7.7	14	29.6%
		8.15	7.95-8.32	14.2	29.2%
Sequential rotation, Waveguide	5.6×5.6×4.7	20	**18-22**	**23.94**	**61.4%**
		30	**28-32**	**26.87**	**53.6%**

lower operating band of the corresponding antenna.

nna. which has no impedance bandwidth due to additional horn antenna as its feed.

AE of RIS：<10%

重要參數 - RCS

影響雷達探測距離其基本的公式

$$P_r = \frac{P_t G_t}{4\pi r^2} \sigma \frac{1}{4\pi r^2} A_{eff}$$

其中

- P_t = 雷達的發射功率（單位：瓦特W）
- G_t = 雷達天線增益（單位：分貝db）
- r = 雷達到探測目標的距離（單位：公尺M）
- σ = 目標的雷達截面積（單位：RCS平方米）
- A_{eff} = 接收天線的有效面積（單位：平方米）
- P_r = 接收到的雷達功率（單位：瓦特W）

#	目標	RCS雷達截面積（M²）
1	**飛機**	
1.1	戰鬥機	3-12[1]
1.2	經匿蹤處理的戰鬥機	0.3-0.4[1]
1.3	戰術轟炸機	7-10
1.4	重型轟炸機	13-20
1.4.1	戰略轟炸機 B-52	100[2]
1.4	運輸機	40-70
2	**艦艇**	
2.1	水下航行的潛艦	0[3]
2.2	獨木舟	50
2.3	飛彈快艇	500
2.4	驅逐艦	10000
2.5	航空母艦	50000[4]
3	**地面目標**	
3.1	汽車	3-10(波長1公分)[5]
3.2	T-90主力戰車（波長 3-8mm）	29[6][7]

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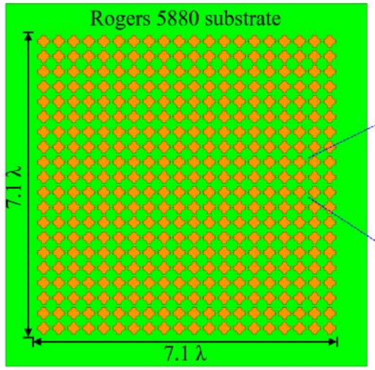
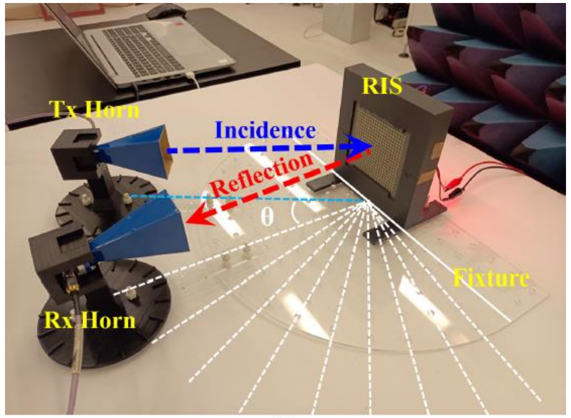
參考文獻 – Open Site

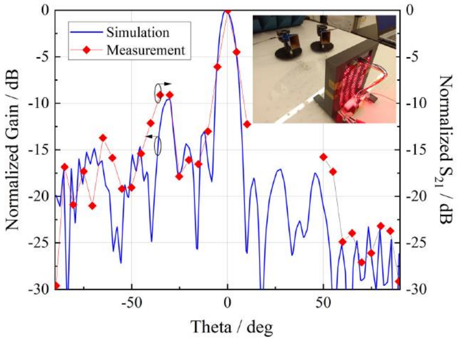
IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 72, NO. 3, MARCH 2024 239

A Wideband Reconfigurable Intelligent Surface for 5G Millimeter-Wave Applications

Ruiqi Wang, Yiming Yang, *Graduate Student Member, IEEE*, Behrooz Makki, *Senior Member, IEEE*, and Atif Shamim, *Fellow, IEEE*







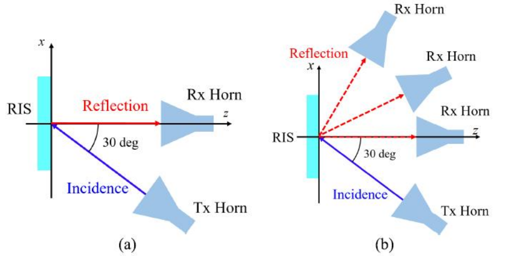
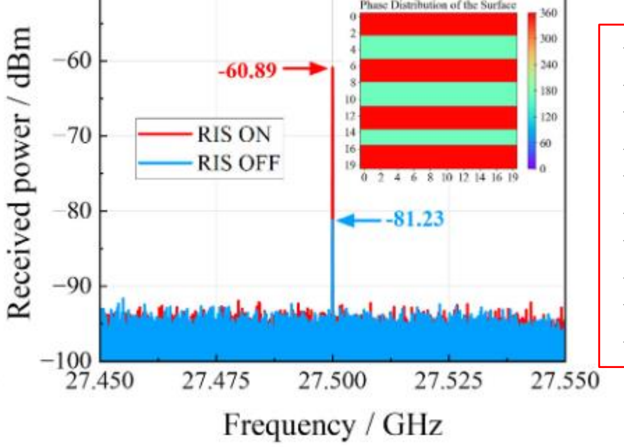
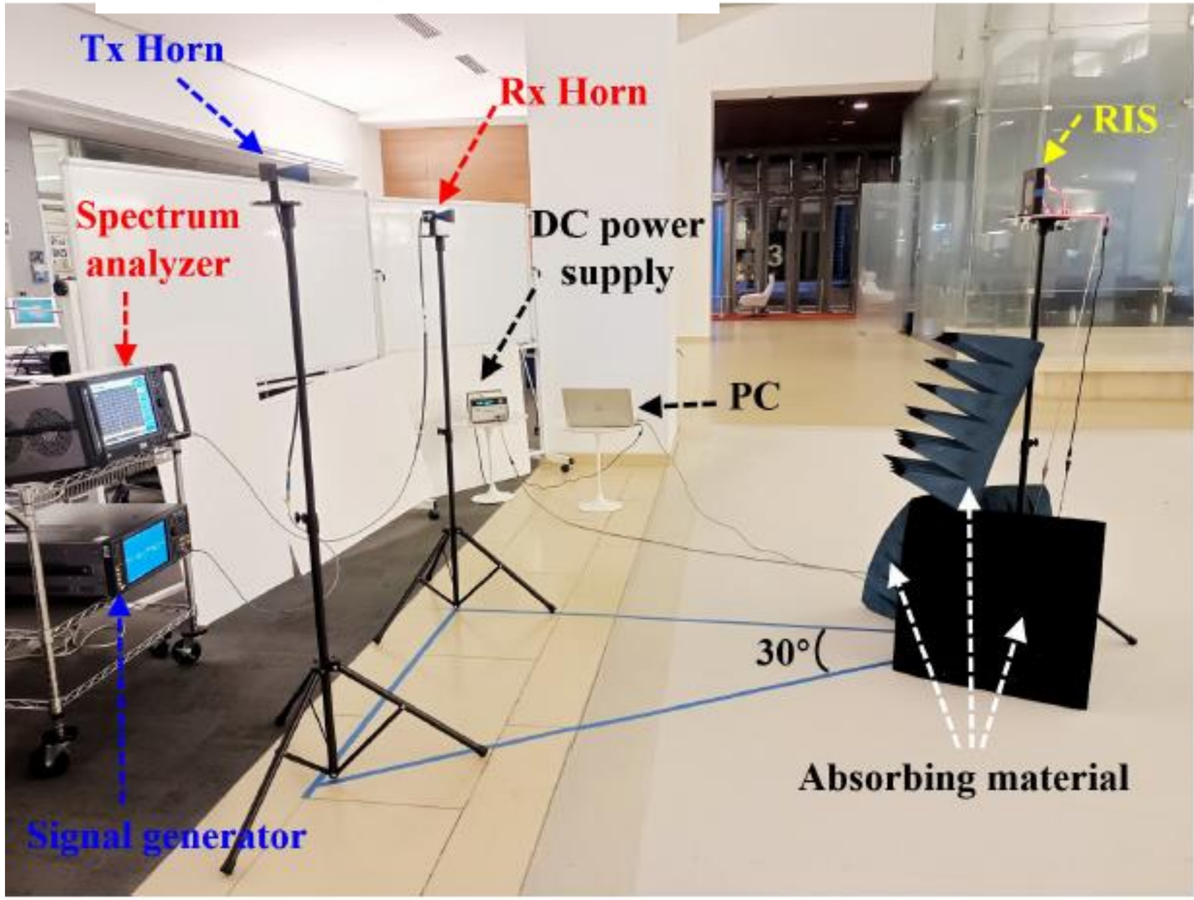


Fig. 17. Measurement scheme. (a) Wideband performance of the proposed RIS. (b) Beam scanning performance of the proposed RIS.



- 目前最常見方法
- 環境干擾
- 單角度量測
- QZ
- Tx/Rx Isolation?



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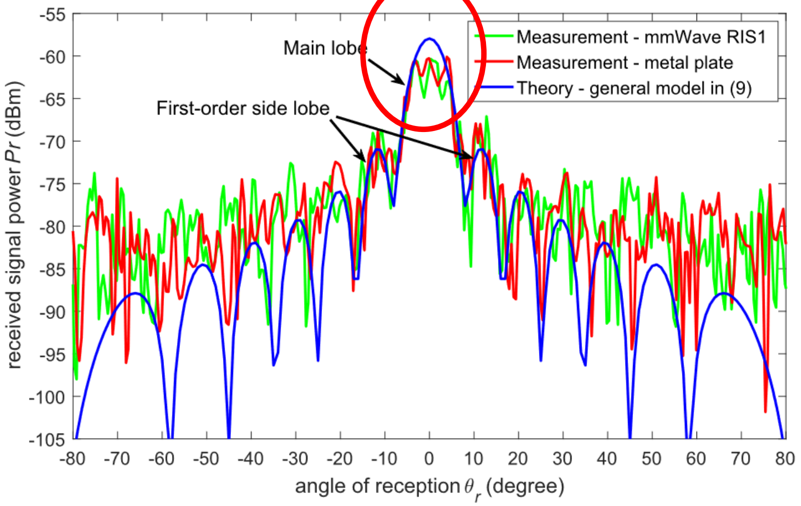
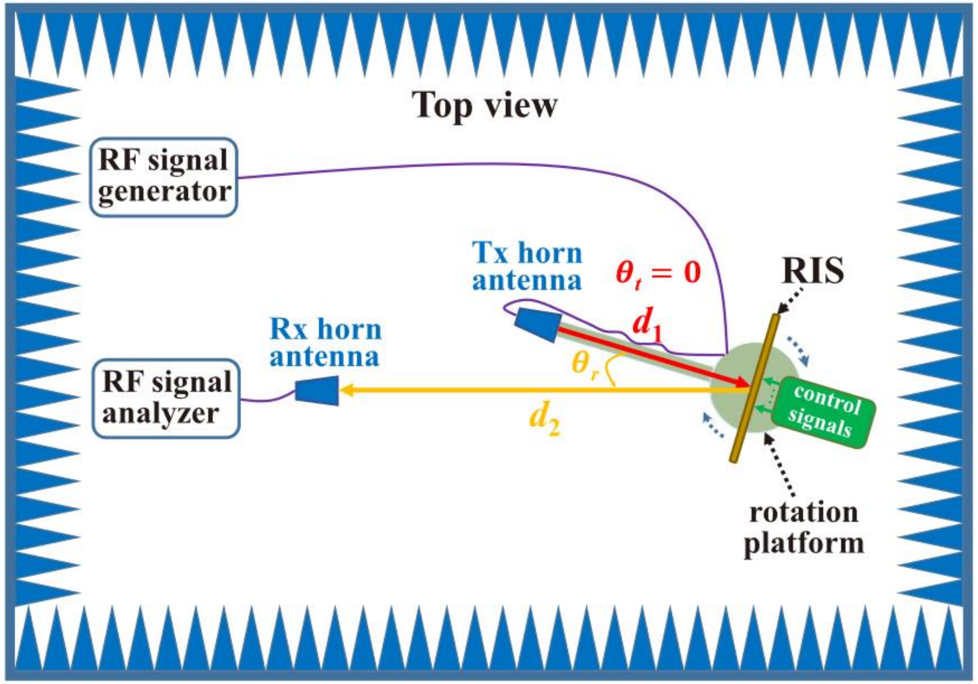
參考文獻 – Anechoic Chamber

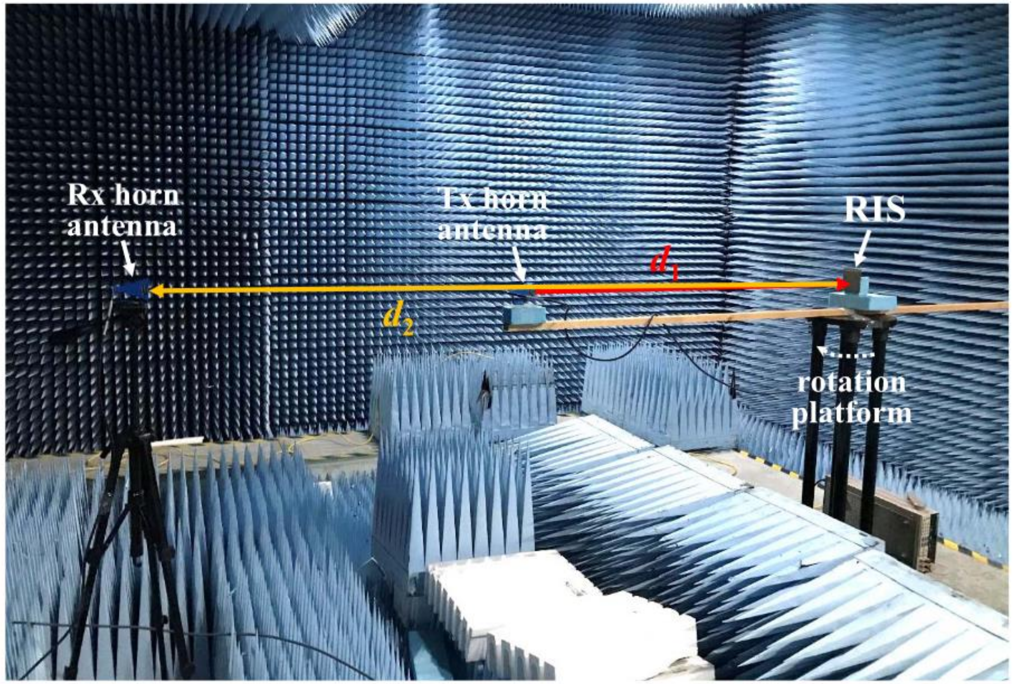
IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 70, NO. 9, SEPTEMBER 2022

Path Loss Modeling and Measurements for Reconfigurable Intelligent Surfaces in the Millimeter-Wave Frequency Band



- 直接遠場 * 2
- AoA固定
- 2D輻射場型
- AoA/AoD相同?
- Tx/Rx Isolation?



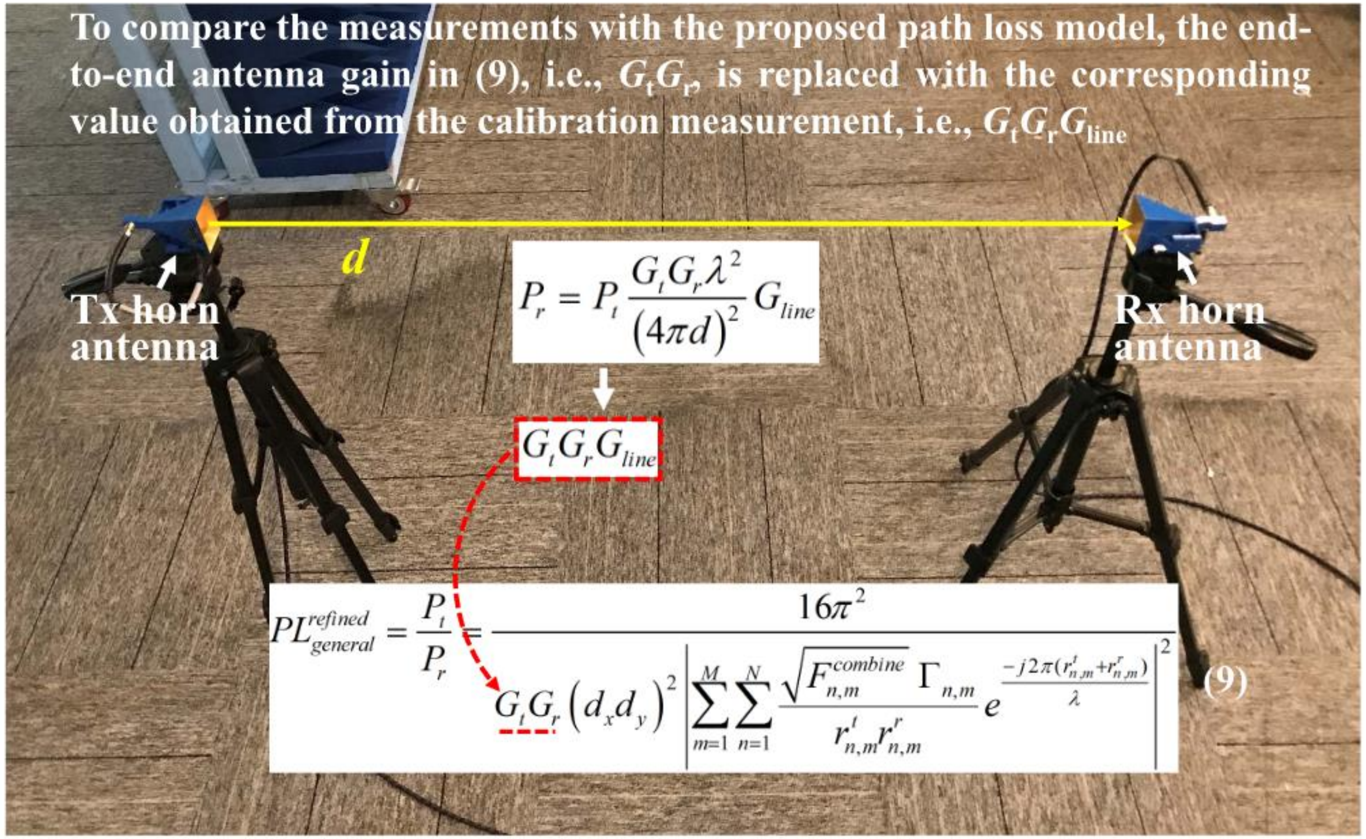


參考文獻 – Path Loss校正

IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 70, NO. 9, SEPTEMBER 2022

System Name	Operating Frequency	Measured Calibration Parameter
Measurement system A	$f = 27$ GHz	$G_t G_r G_{line} = 2.9$ dB
Measurement system B	$f = 27$ GHz	$G_t G_r G_{line} = 24.0$ dB
Measurement system B	$f = 33$ GHz	$G_t G_r G_{line} = 22.0$ dB

- G_{line}
- 相位中心
- 極化
- 相對位置
- Multi-path
- QZ



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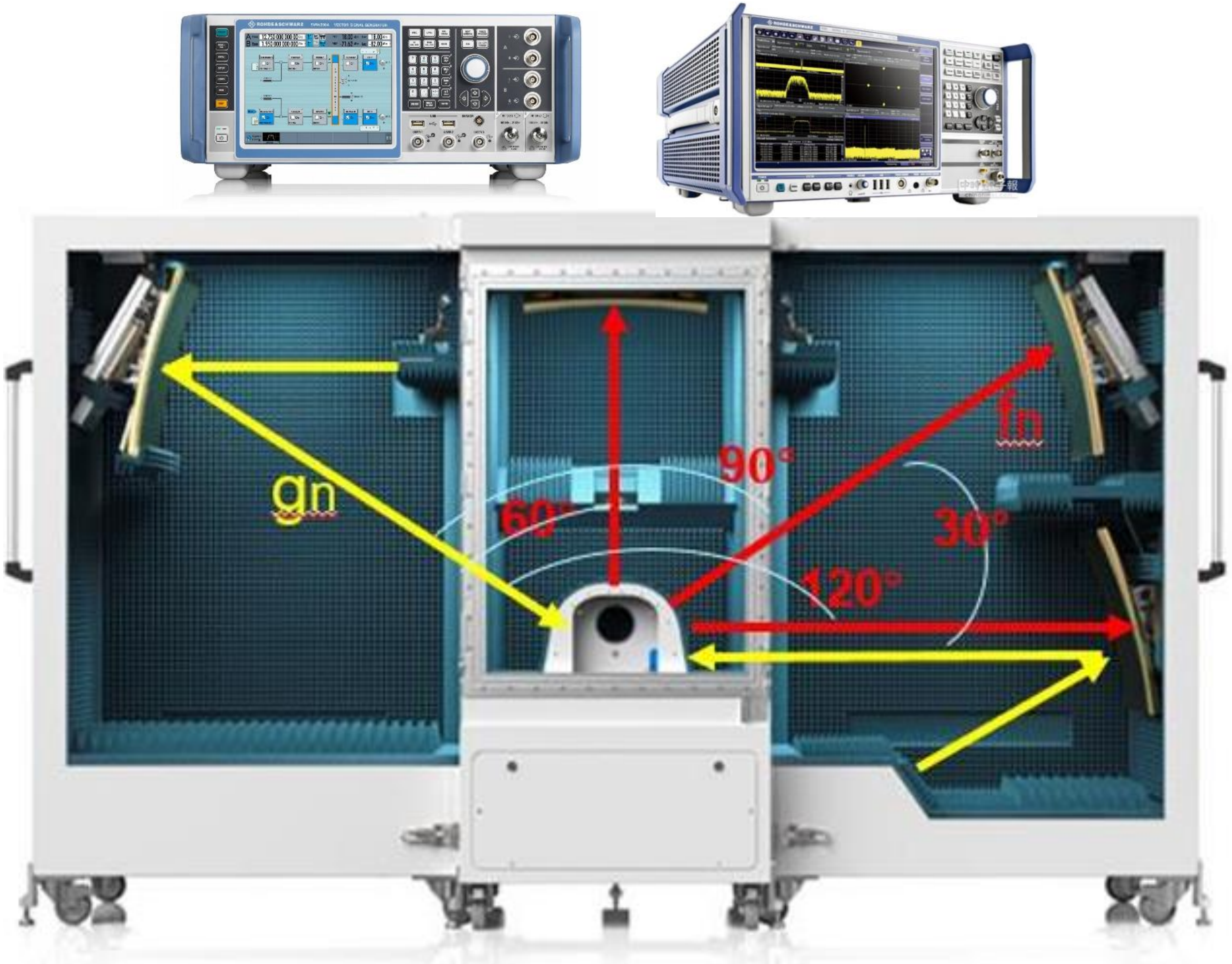
參考文獻 - Active

- 雙CATR
- 特定AoA/AoD
- EIRP/EVM/ACLR

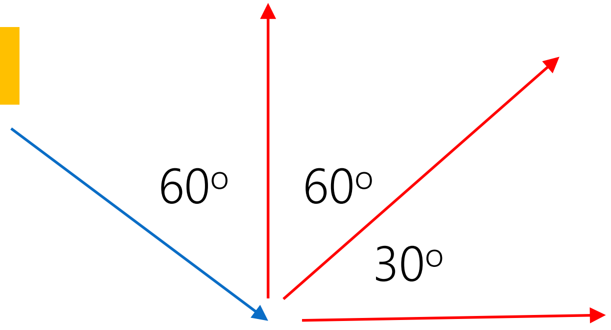
SMW200A

FSW

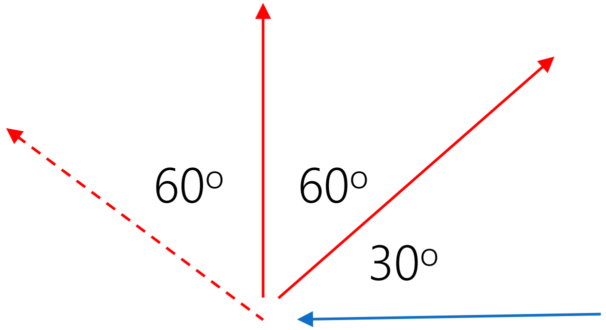


60度/120度/150度

入射1



30度/90度



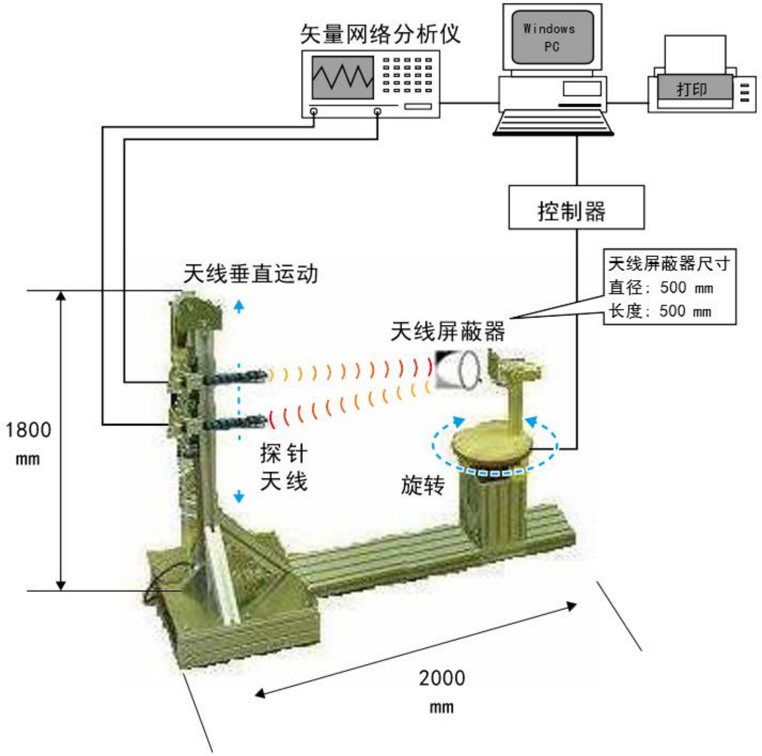
入射2

資料來源：2023 RISTA技術白皮書

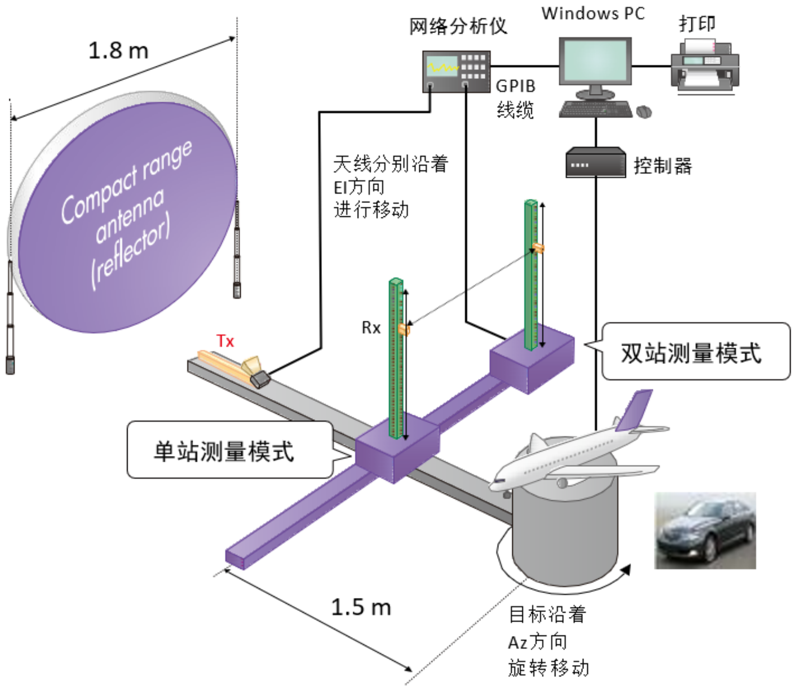
參考文獻 – RCS量測

- AoA固定
- 2D輻射場型
- AoA/AoD相同?
- Tx/Rx Isolation?

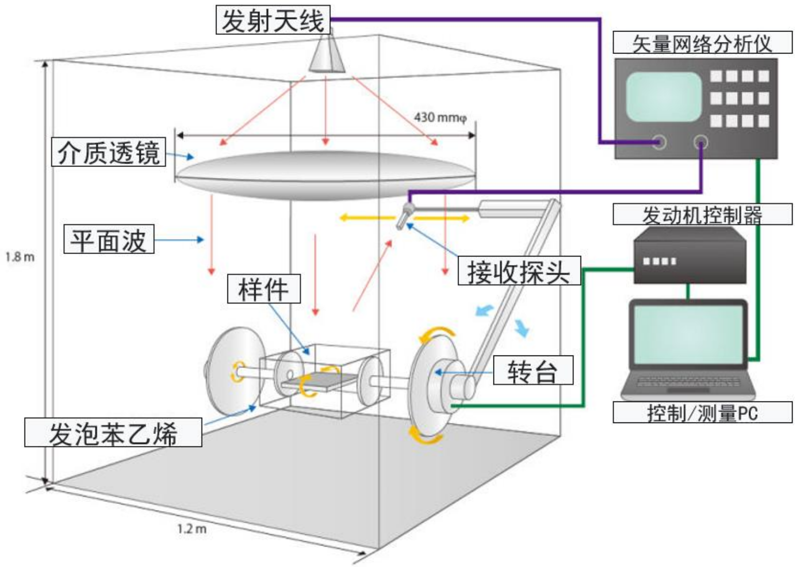
直接遠場*2



CATR + 直接遠場

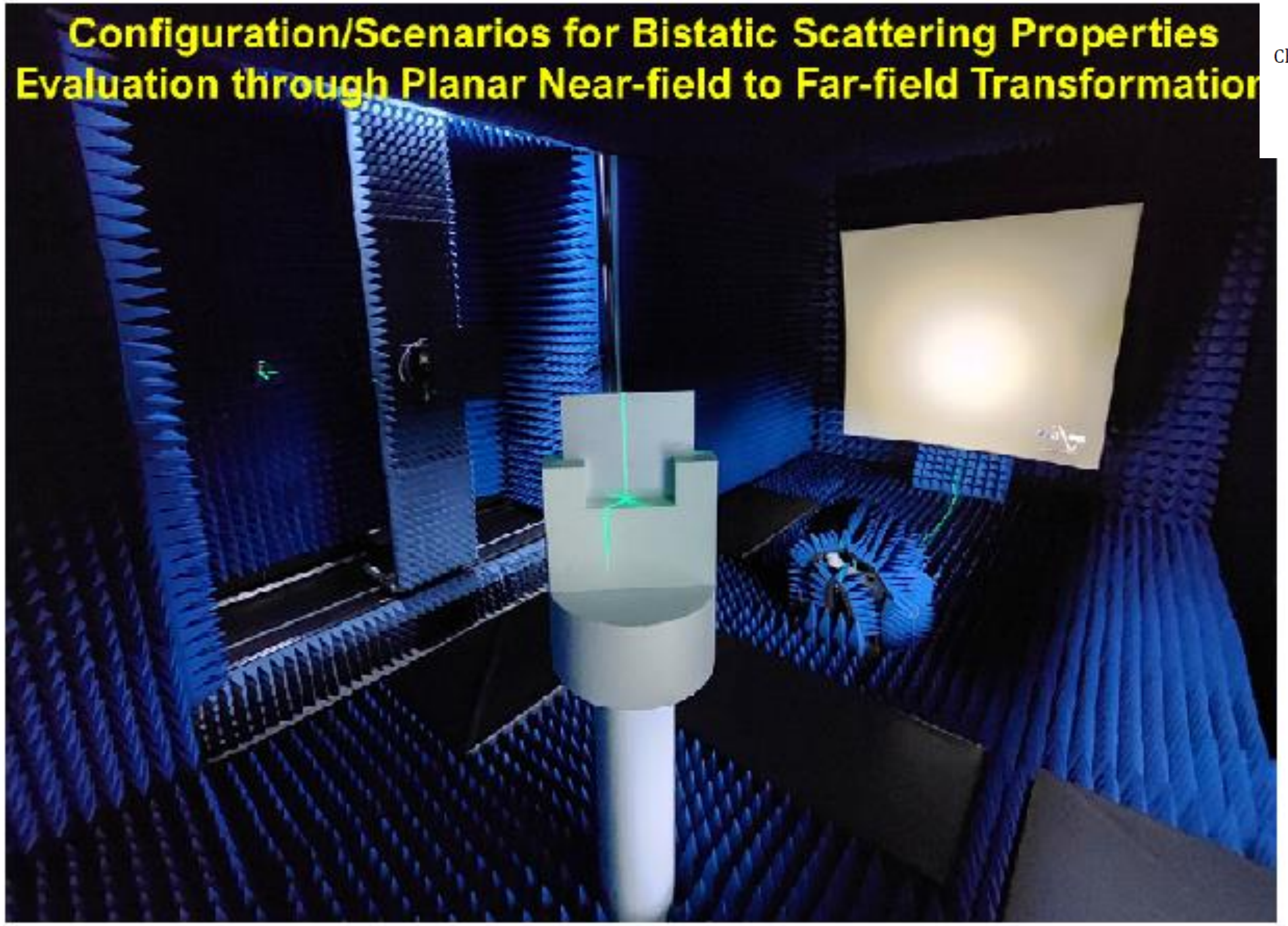


CATR(Lens) + 直接遠場



https://keycom.co.jp/cmap/xrc.html

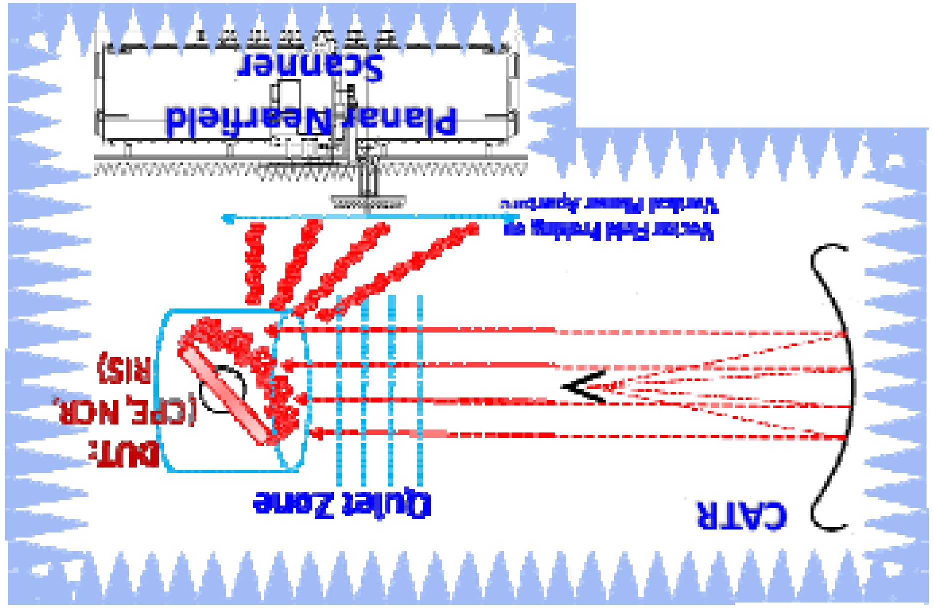
參考文獻 – CATR + NF



Performance Evaluation of RU and RIS Based on OTA Mode Near Field and Bistatic Measurement Systems

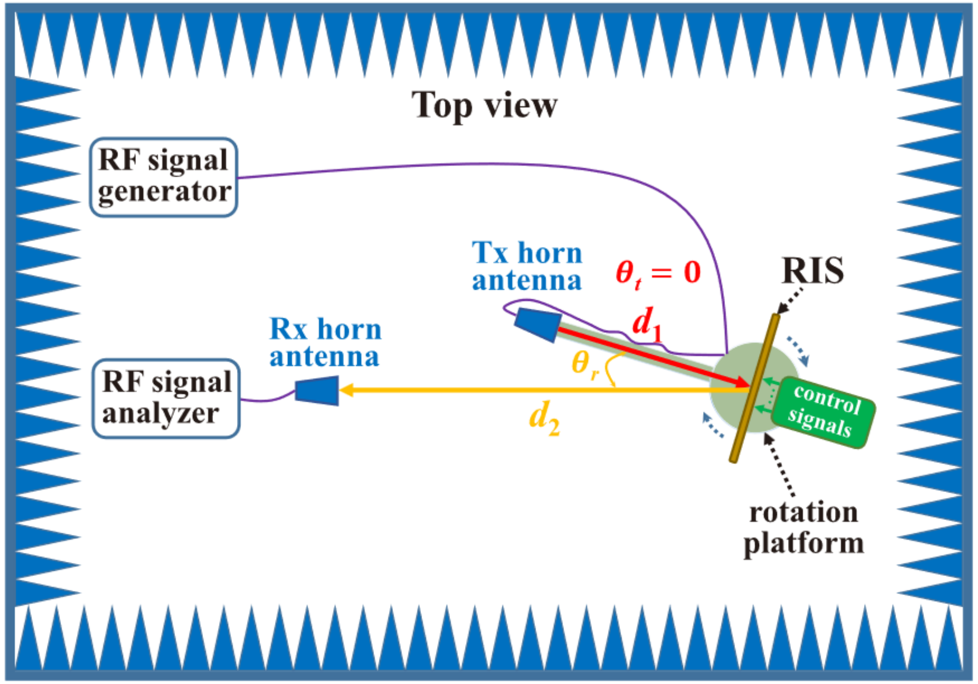
Chang-Lun Liao [1,2], *Student Member, AMTA,* You-Hua Lin [1,3], *Student Member, AMTA,* Ike Lin [3], *Member, AMTA,* and Chang-Fa Yang [1], *Member, AMTA.*

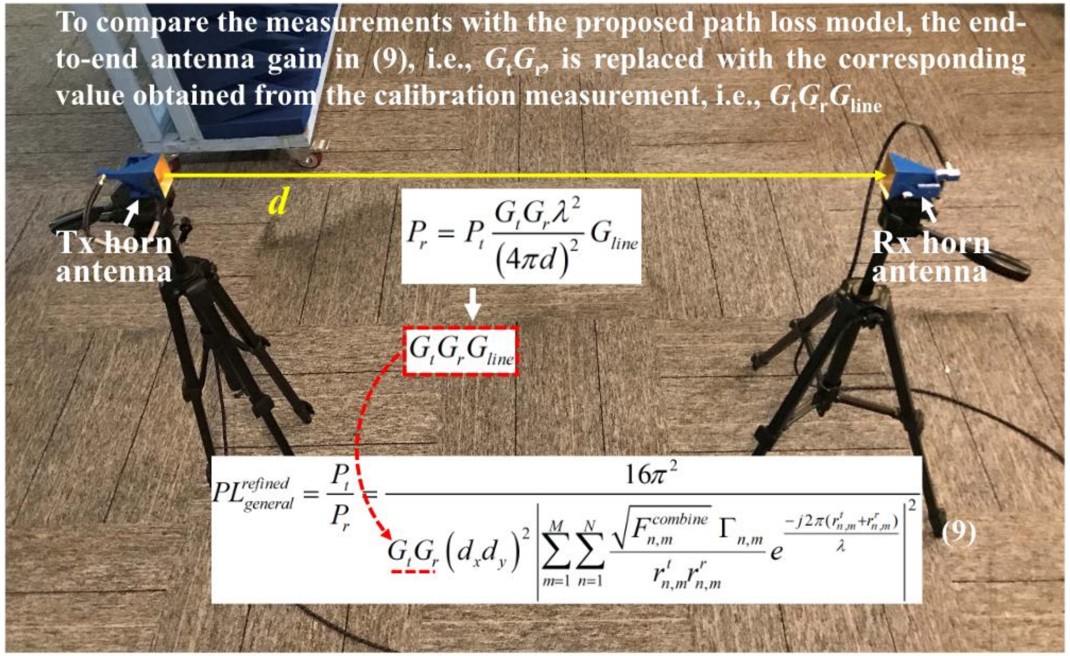
[1] Department of Electrical Engineering, National Taiwan University of Science and Technology (Taiwan Tech), Taiwan
[2] Wireless Communications Laboratory, Chunghwa Telecom Laboratories, Taiwan
[3] WaveFidelity Inc., Taiwan



- CATR + 平面近場
- AoA/AoD涵蓋範圍小
- 平面近場轉換複雜

挑戰





- Bistatic (Planar wave*2) ➔ QZ大
- AoA/AoD有效角度

- Path Loss校正

大綱

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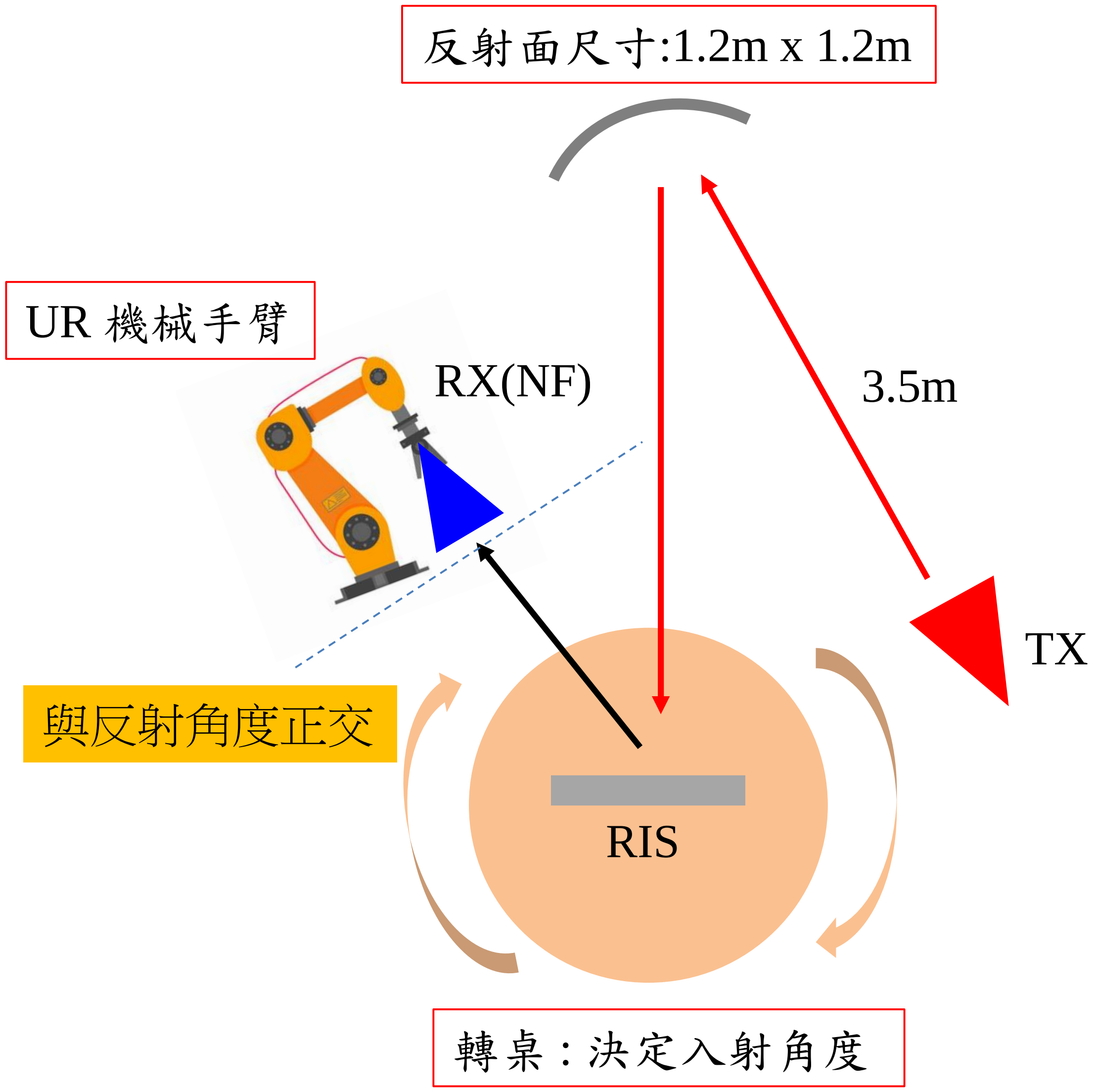
- 結論

RIS OTA量測系統設計



QZ : 60cm

Tx : CATR
120cm反射面

Rx : 平面近場
掃描平面定義

CATR QZ分析

平面近場條件分析

Link budget

Isolation及散射問題處理

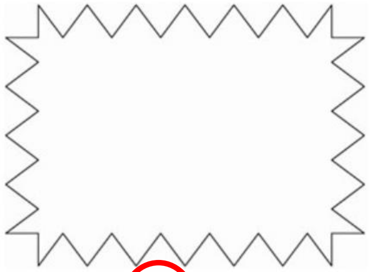
Path Loss校正

3D+自動化

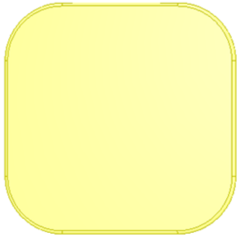
QZ分析

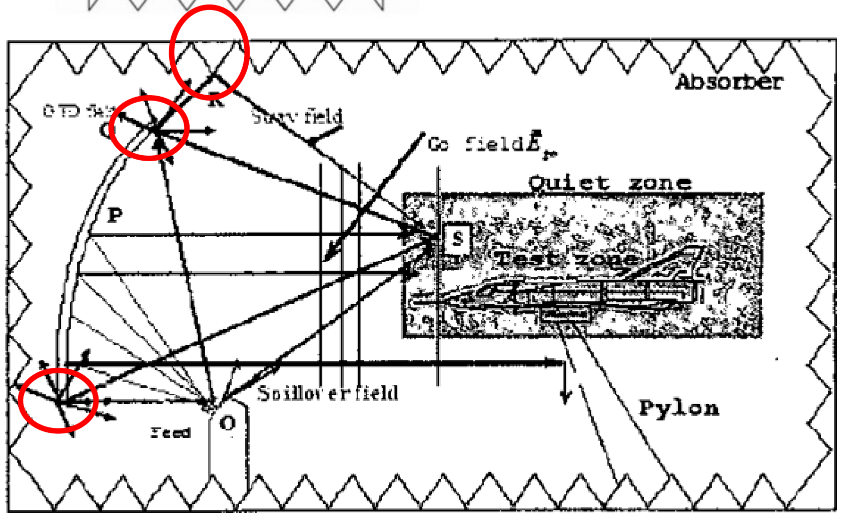
Edge treatment

Serrated Edge



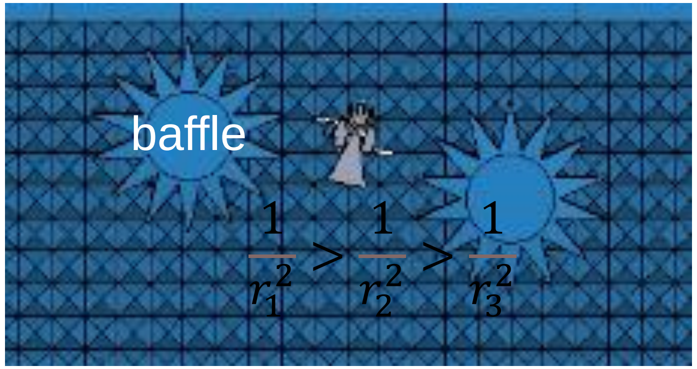
rolled edge



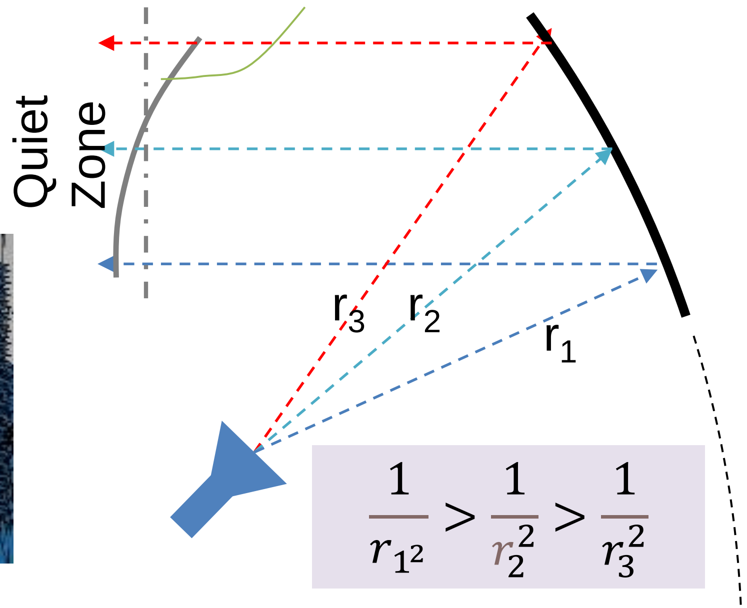


Chang, Dau-Chyrh et al. “Compact antenna test range without reflector edge treatment and RF anechoic chamber.” IEEE Antennas and Propagation Magazine 46 (2004): 27-37.

Unwanted radiation treatment



Amplitude taper

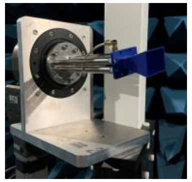


Feed antenna

Wide band

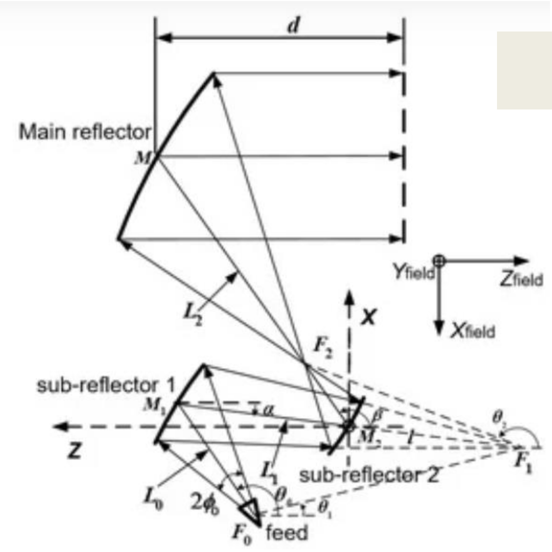
Stable phase center

Rotational CP feed antenna



Low X-pol

Low X-pol



https://doi.org/10.3390/electronics10141727

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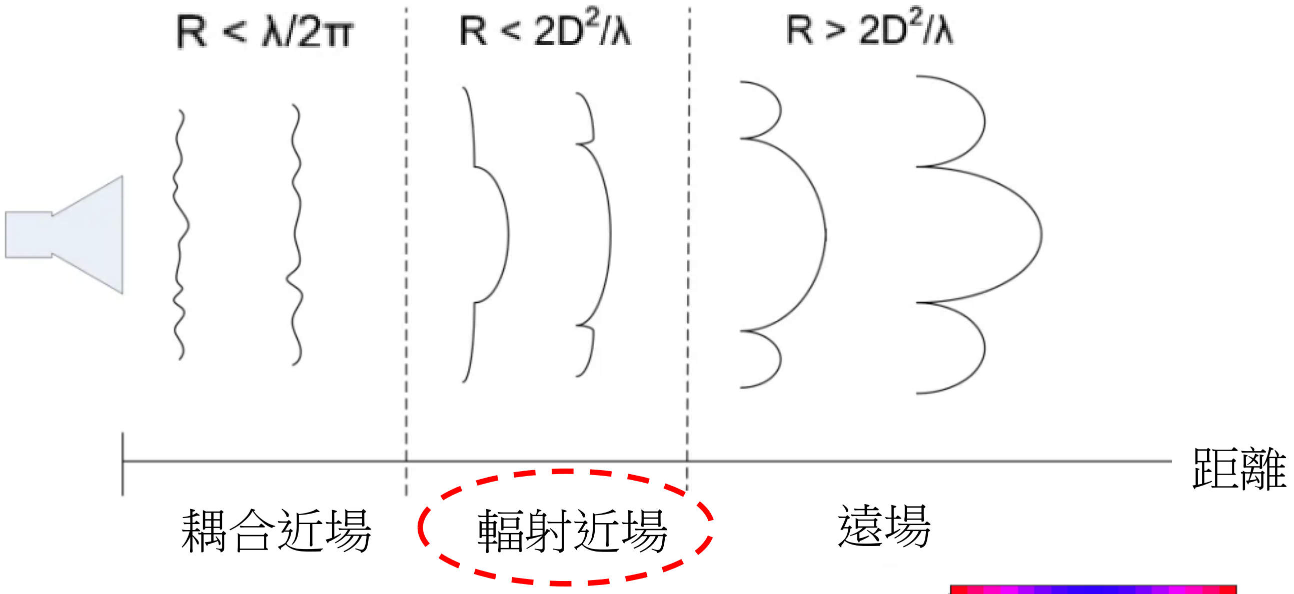
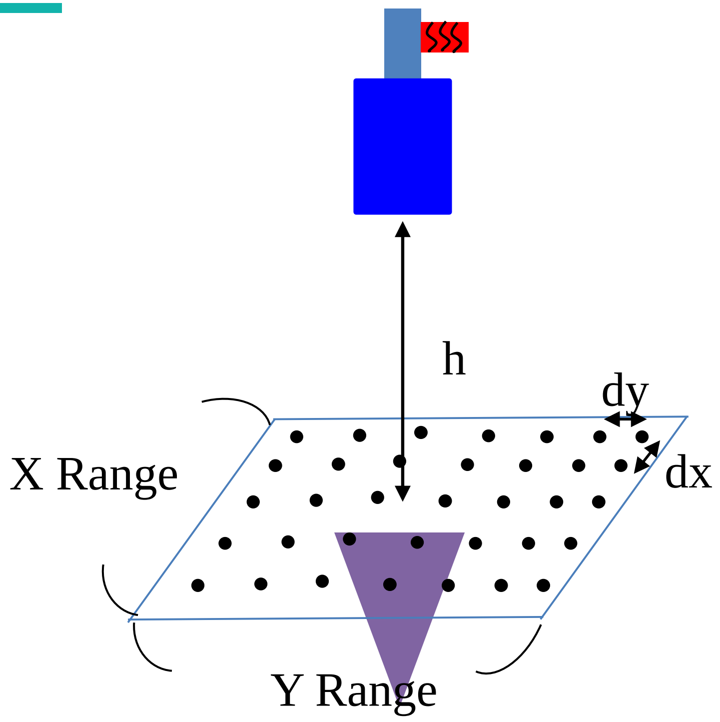
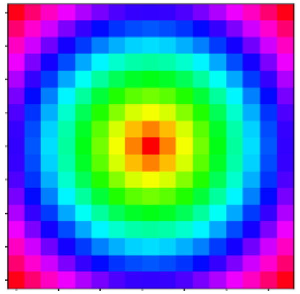
近場量測原則說明





近場量測: 輻射近場(球面波)



遠場量測: 遠場(平面波)

dx/dy : <1/2 0; h決定有效涵蓋角度/時間

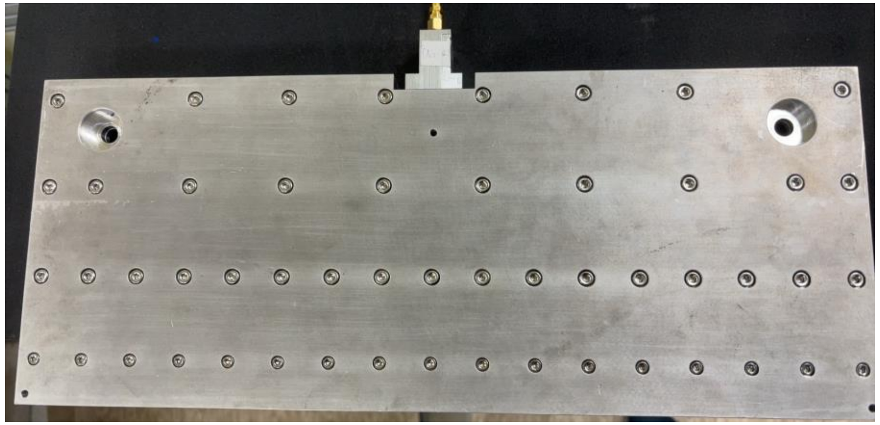
再利用程式進行轉換至遠場

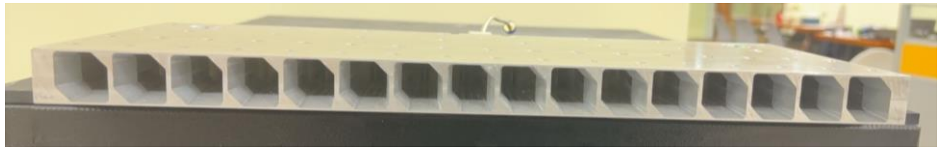
Path Loss校正

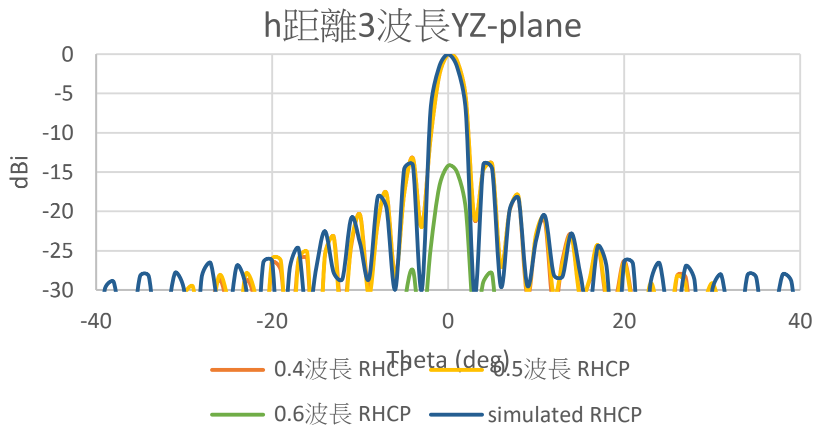
NF系統&AUT說明

取樣間距 : 2mm(約0.1波長)
平面大小: 60cm X 60cm

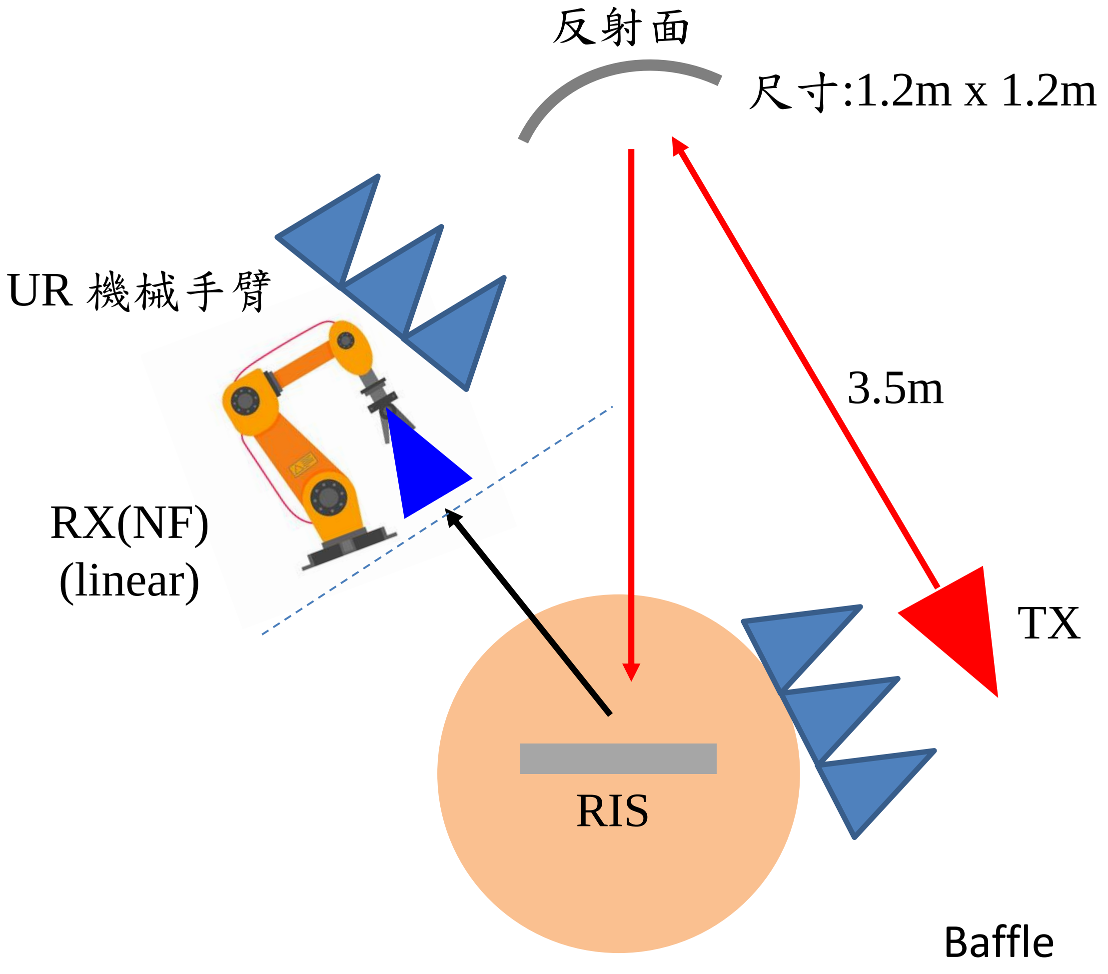
DUT尺寸:40cm x 2.5cm





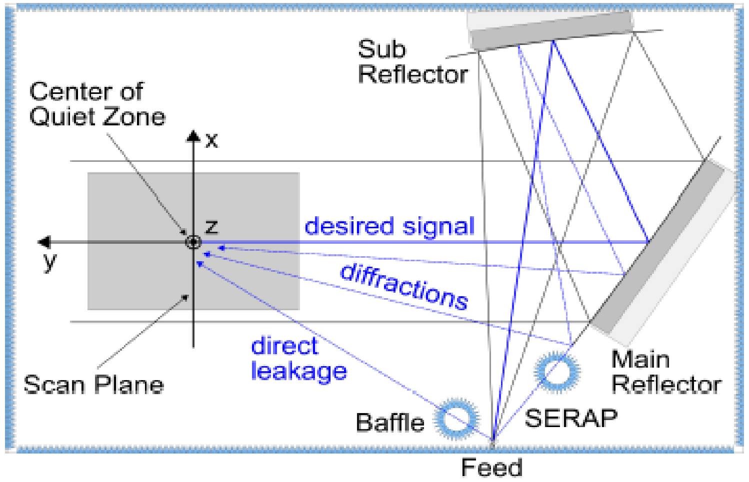


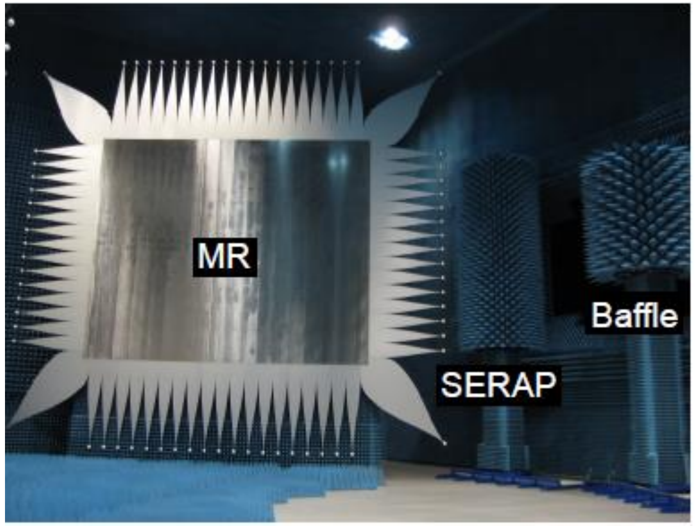
Isolation & Scattering Effect issue



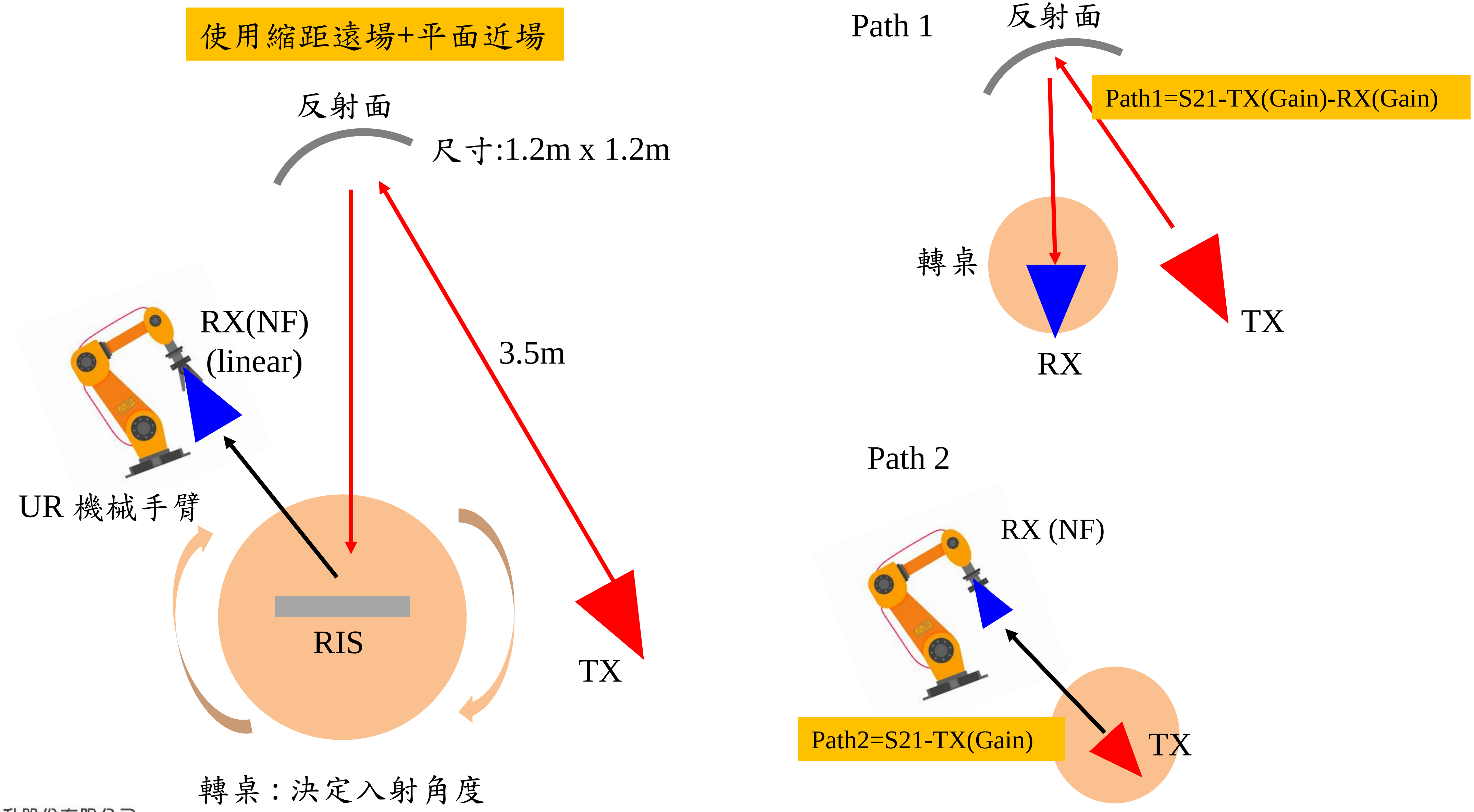
Full-Wave Analysis of Compensated Compact Ranges Including Absorber Structures

T. M. Gemmer, C. H. Schmidt, A. Geise, J. Migl
Airbus Defence & Space, 81663 Munich, Germany, thomas_gemmer@gmx.de, carsten.schmidt@airbus.com

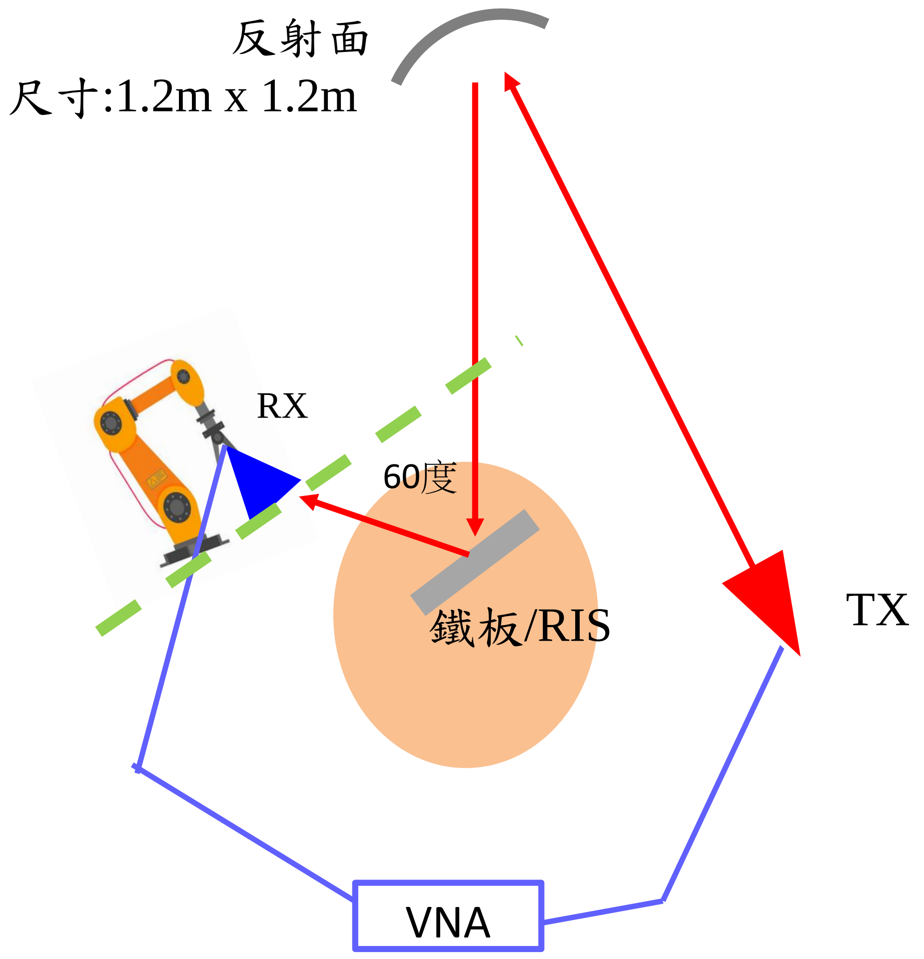


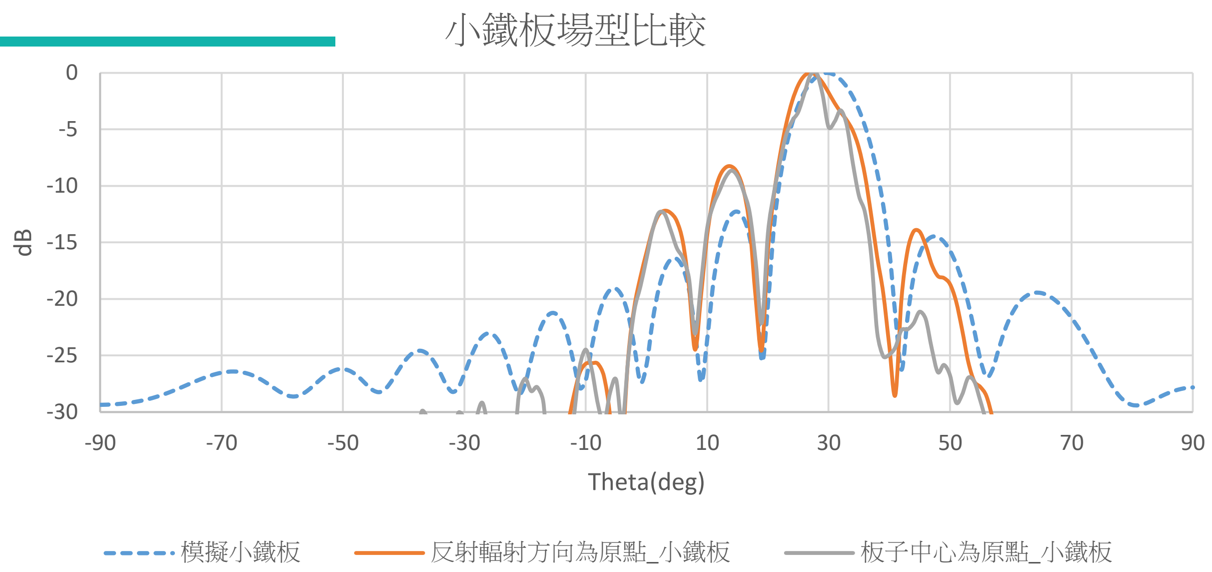


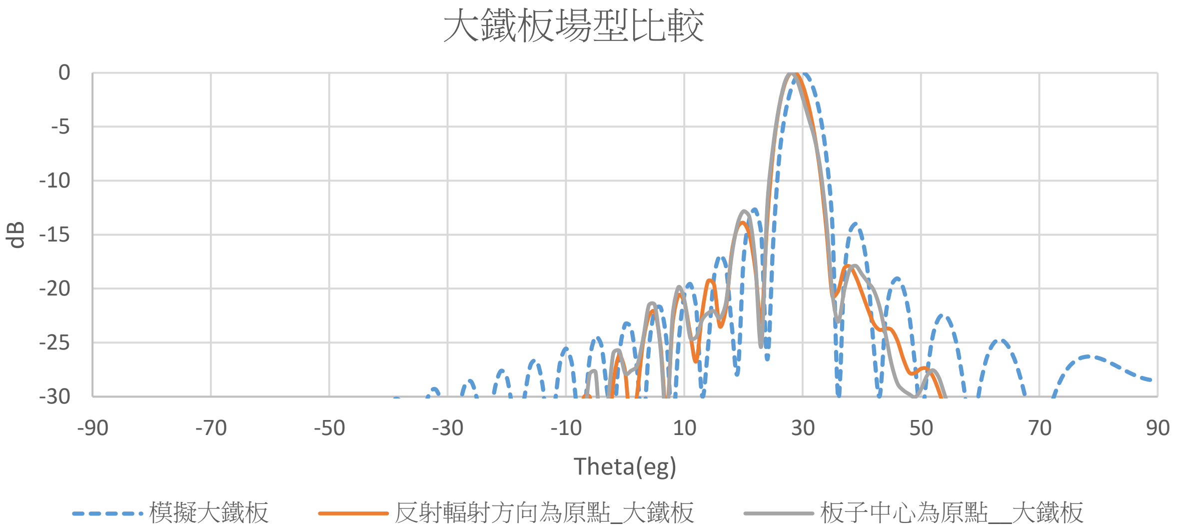
Path Loss校正-SGH分段



Path Loss校正-替代法



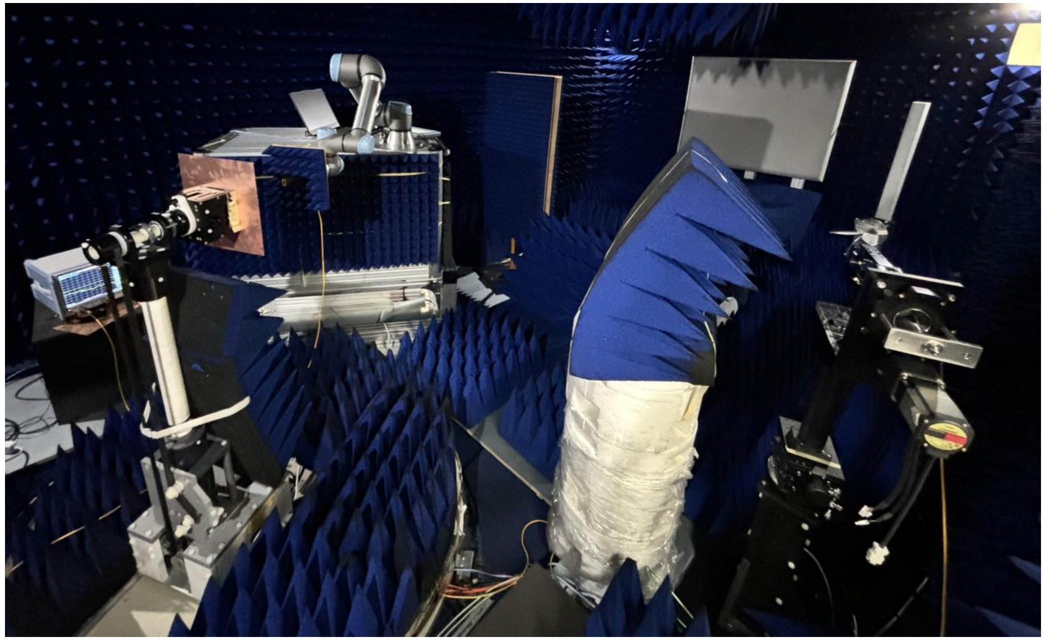




以反射輻射方向為原點進行量測 ➔ 有效角度

不同AoA/AoD Aperture size不同

鐵板Path Loss差異

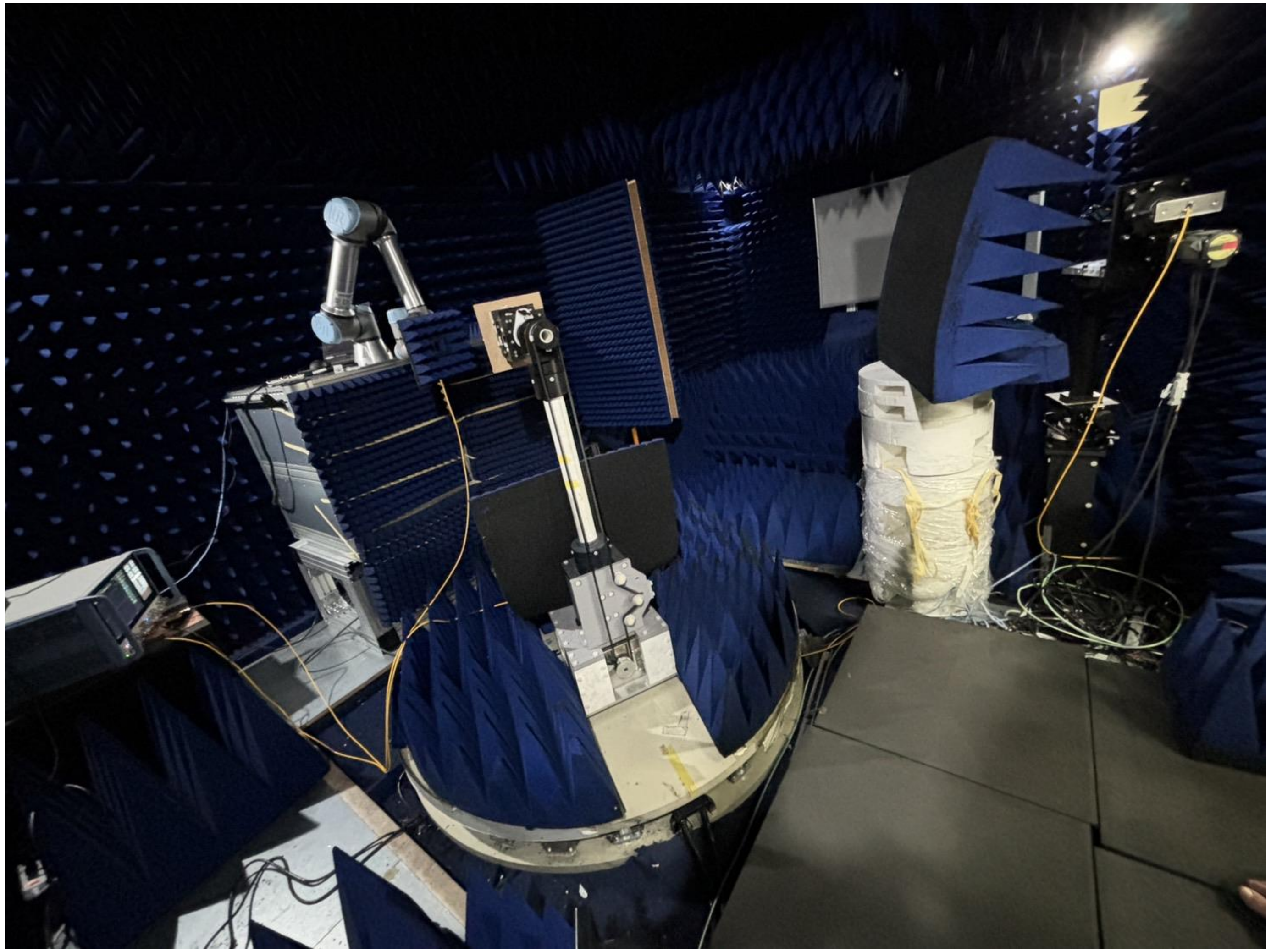


Path Loss 為量測值-模擬Gain
三種鐵板之間最大差異為1.1 dB

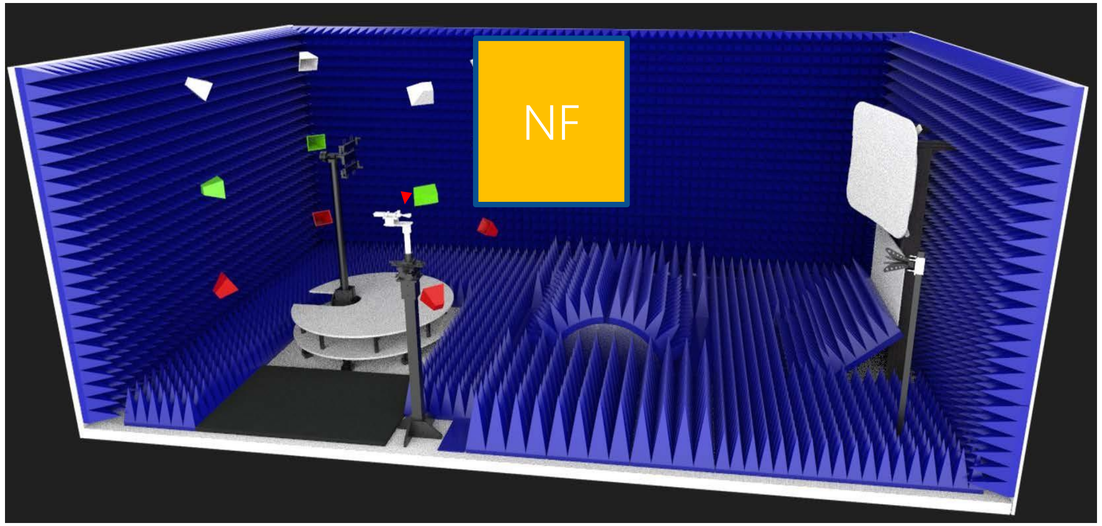
差異來源我認為是QZ不理想原因較大
因為發射天線並非為設計過的CATR發射天線
所以還是需要看待測物大小變更鐵板大小

	28 * 28 cm		**20 *20 cm**		**15 * 15 cm**
反射輻射方向為中心(量測值)	-65.2 dB	5.0	-70.2 dB	5.3	-75.5 dB
模擬gain	18.6 dBi	6.1	12.5 dBi	4.9	7.6 dBi
Path Loss	-83.8 dB		-82.7 dB		-83.1 dB

架構尺寸



System specification (typical)	
External Dimension	7× 4 × 3 m^3 (L × W × H)
Reflector Focal length	350 cm
Isolation	> 90 dB (0.6GHz~80GHz)
Absorber	Pyramid type absorber
Reflector specification (typical)	
Frequency range	0.6-80 GHz
Size	120 × 120 cm^2
Edge treatment	Rolled edge
Quite zone size	Diameter 60 cm
Cross polarization isolation	> 30 dB
Amplitude taper	3 dB
Amplitude ripple	±1.5 dB



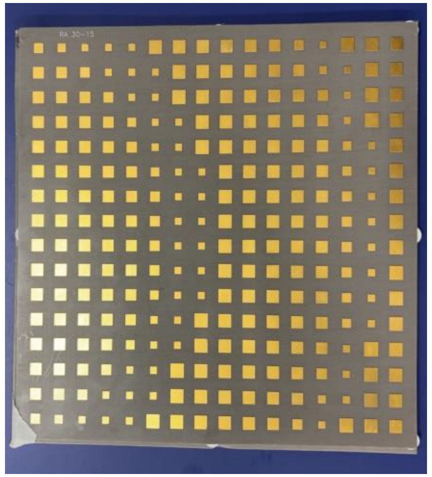
模擬及量測結果

差異可能原因 -
Peak角度 : RIS法向量定位
HPBW : QZ&RIS設計相位

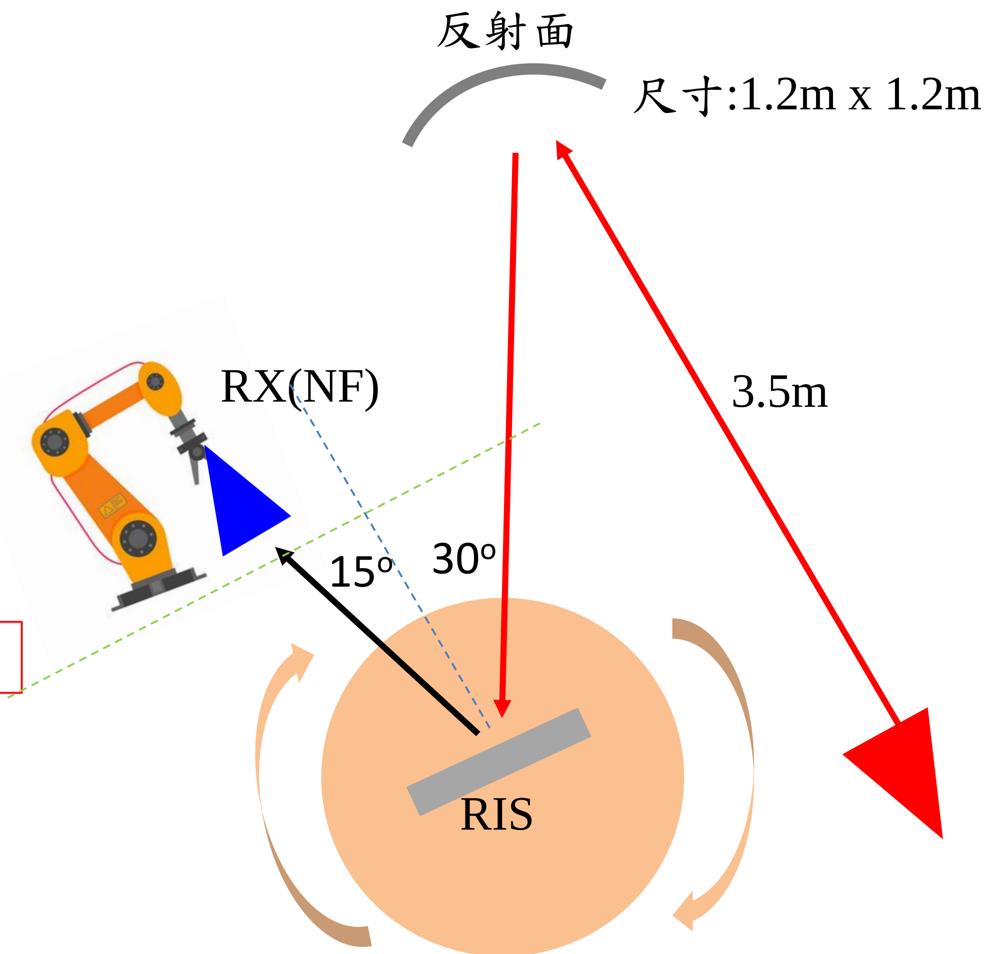
	模擬	量測	差異
Peak 角度	15(30)	17(32)	2(2)
HPBW	8(8)	4(6)	4(2)

( )為同尺寸鐵板結果

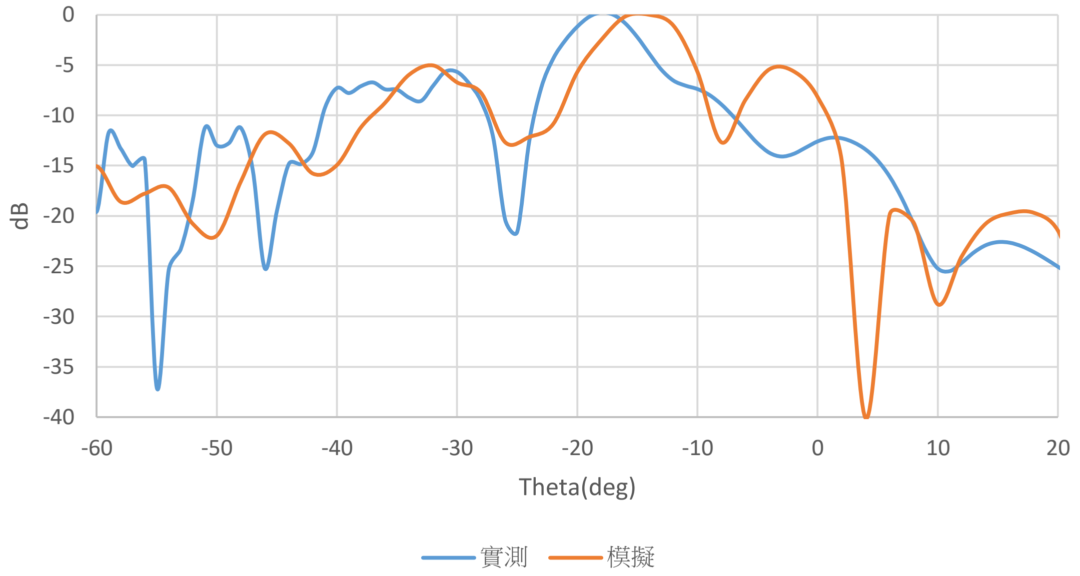
20 *20 cm



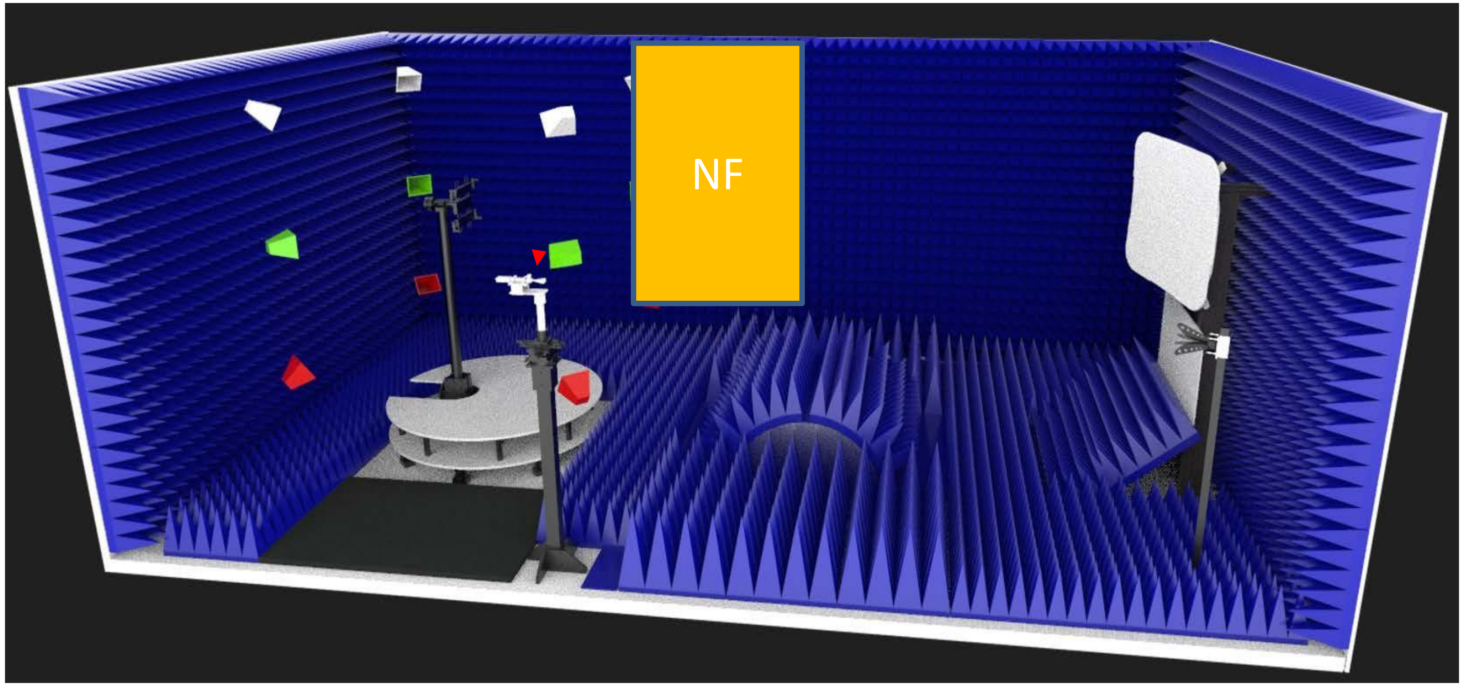
入射:30度；反射:15度



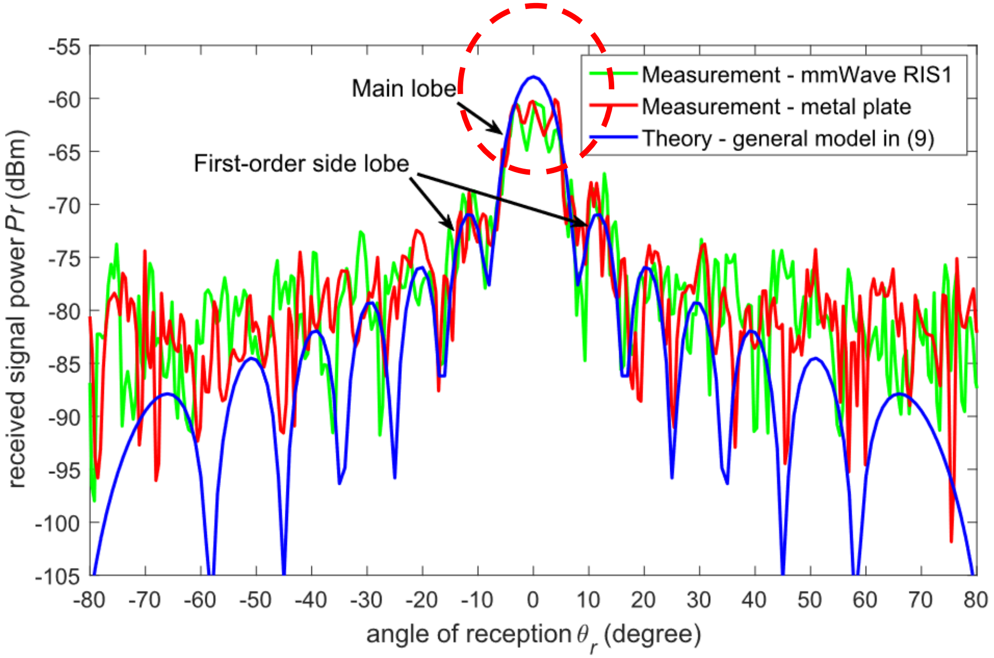
RIS模擬實測場型圖



AoA = AoD條件量測?


NF

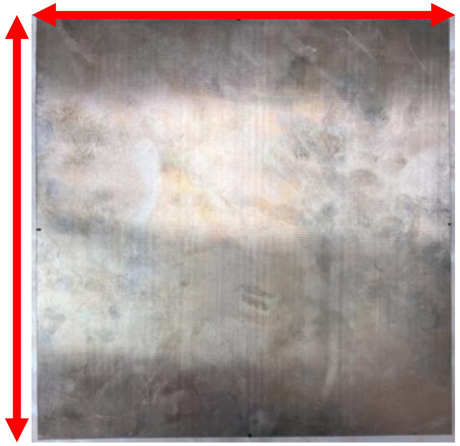

FLAT PLATE


Main lobe
First-order side lobe
Measurement - mmWave RIS1
Measurement - metal plate
Theory - general model in (9)
received signal power Pr (dBm)
angle of reception θr (degree)
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80

雙圓極化量測

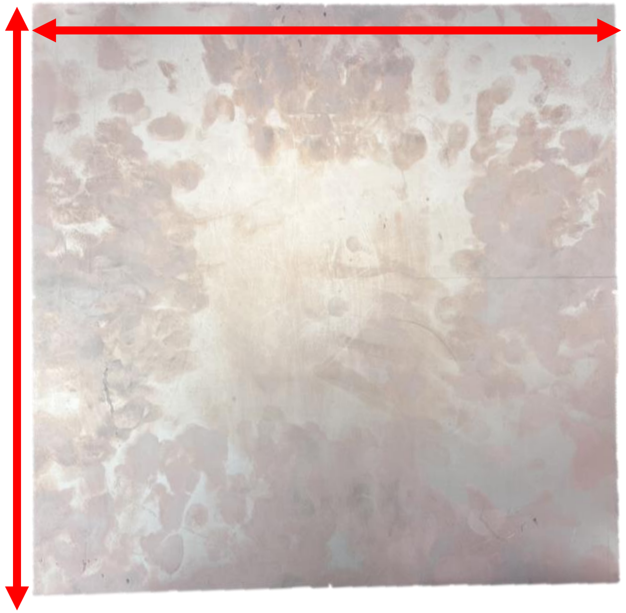
20 cm

20 cm

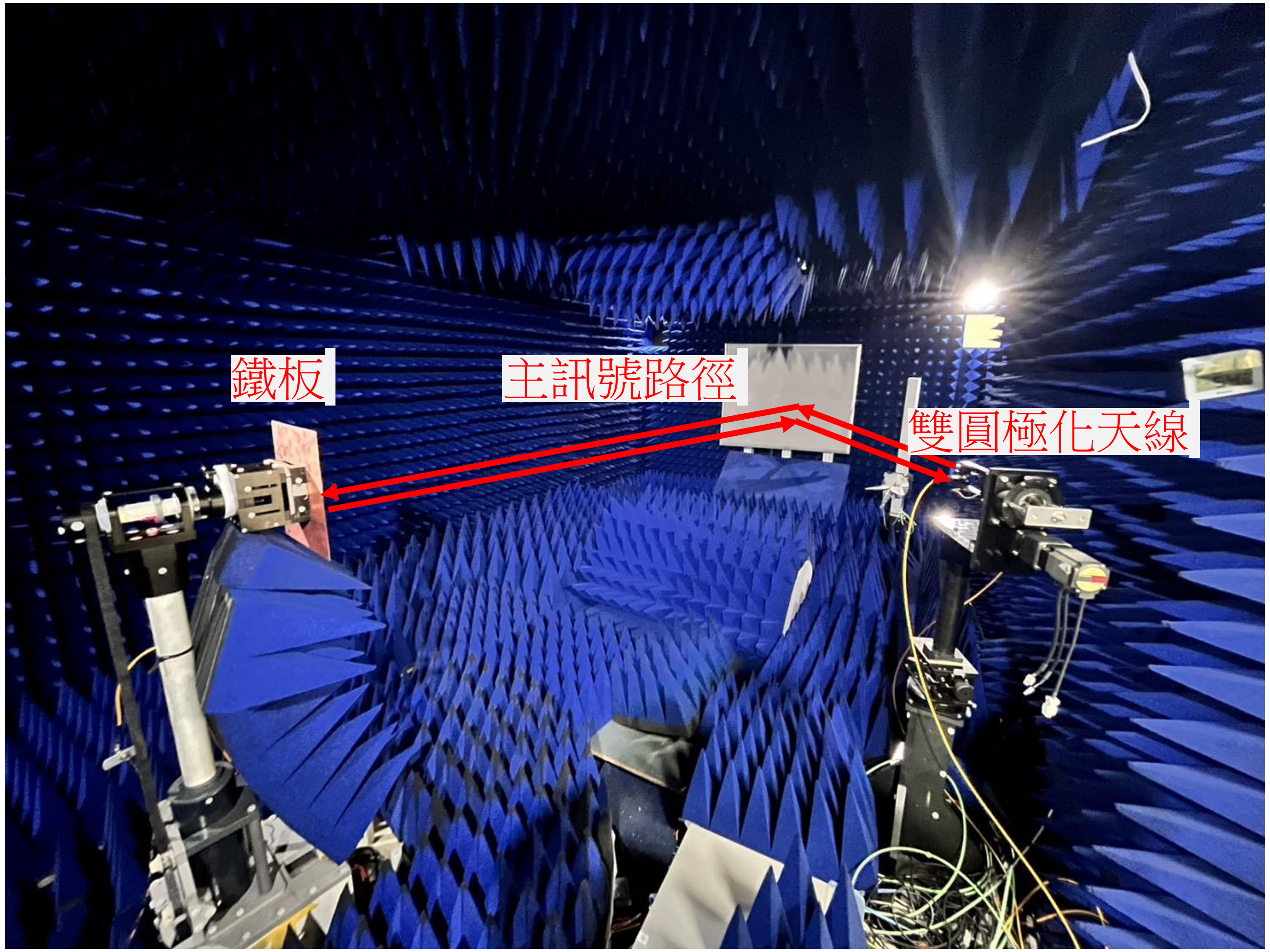


28.5 cm

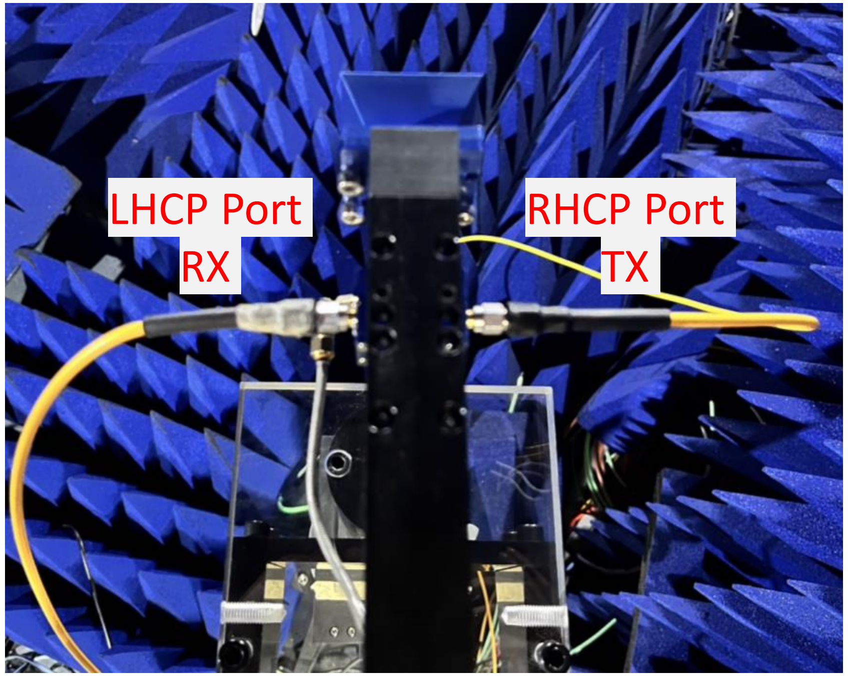
28.5 cm



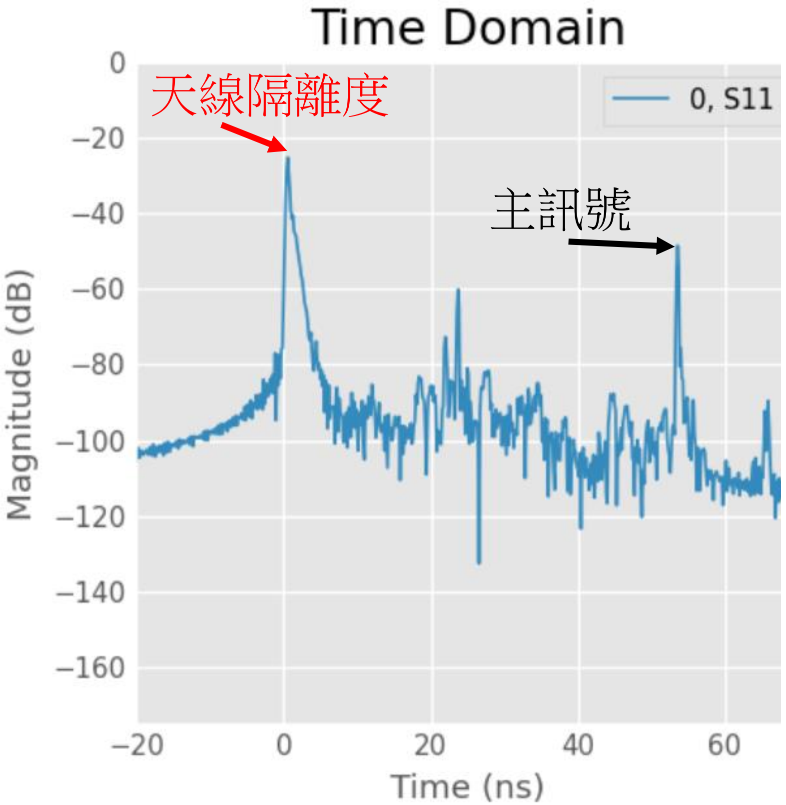
量測環境



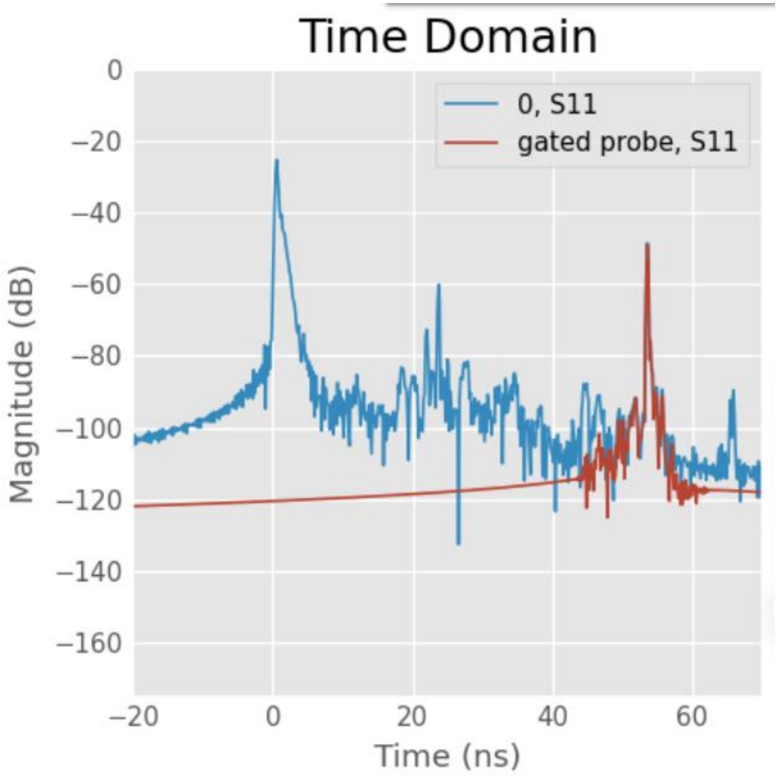
Time Gating



No Time gating

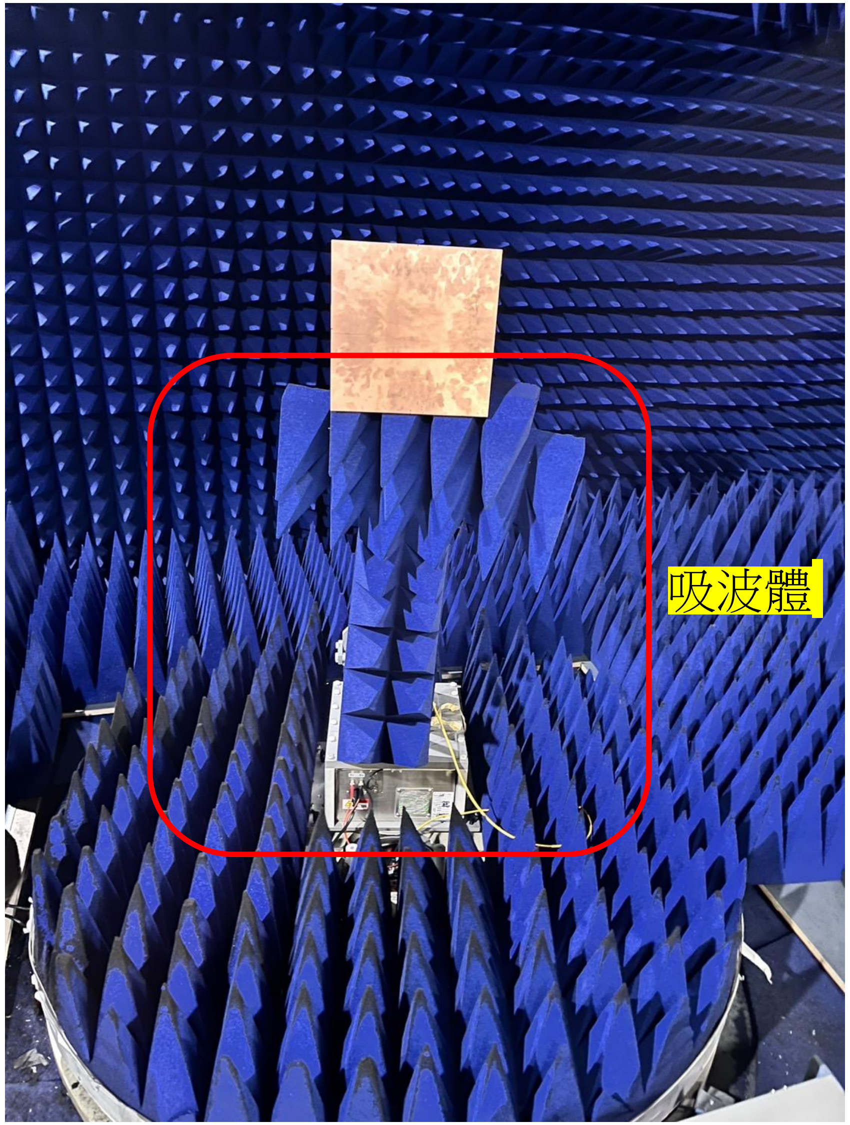


Time gating

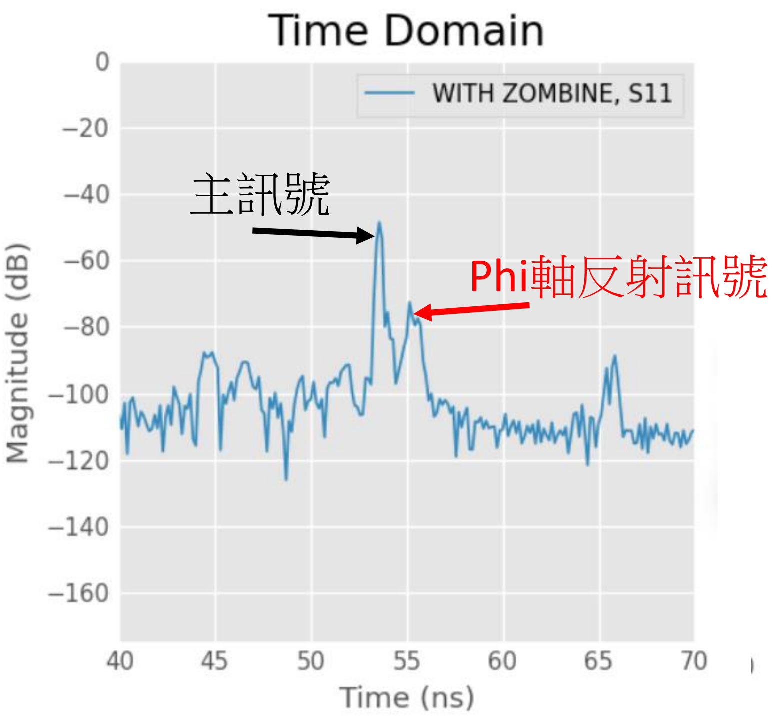


因接收與發射都在同一支天線上，在網儀上會量測到天線隔離度，所以必須用 Time gate 來消除，Time gate的範圍取主訊號左右雜訊牆最低處。

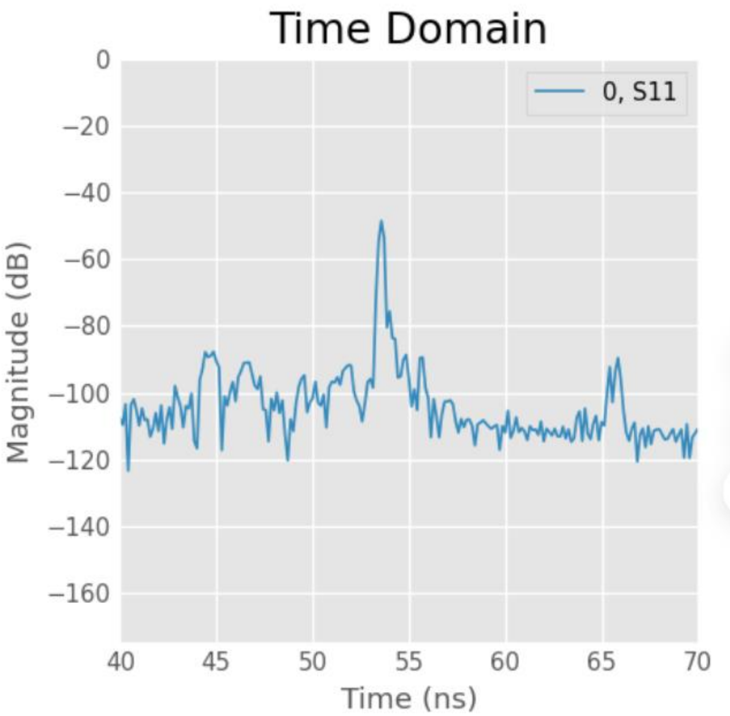
治具散射分析



沒有吸波體



有吸波體

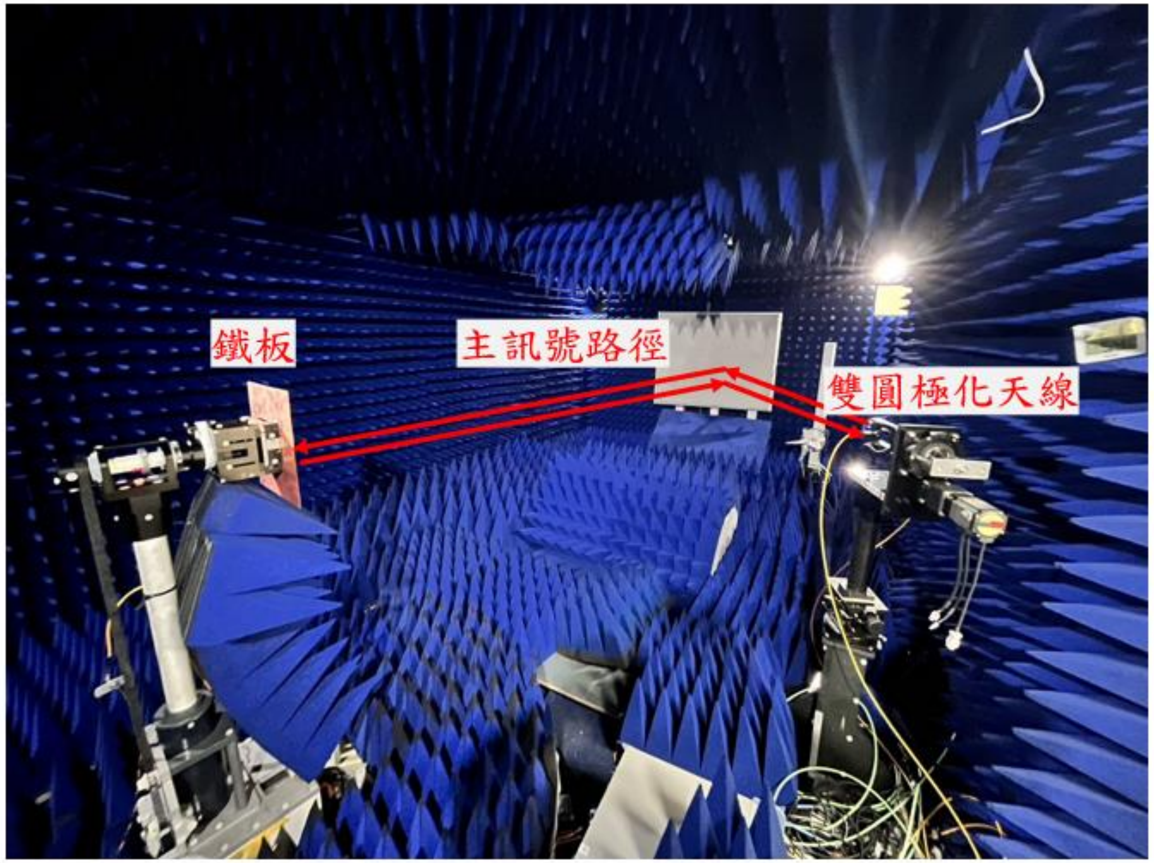


在左上時域圖中，可以發現圖中有兩個較強的訊號，而反射訊號離主訊號太近故無法用time gate 消除，故在Phi軸手臂放滿吸波體。並且反射訊號消失。

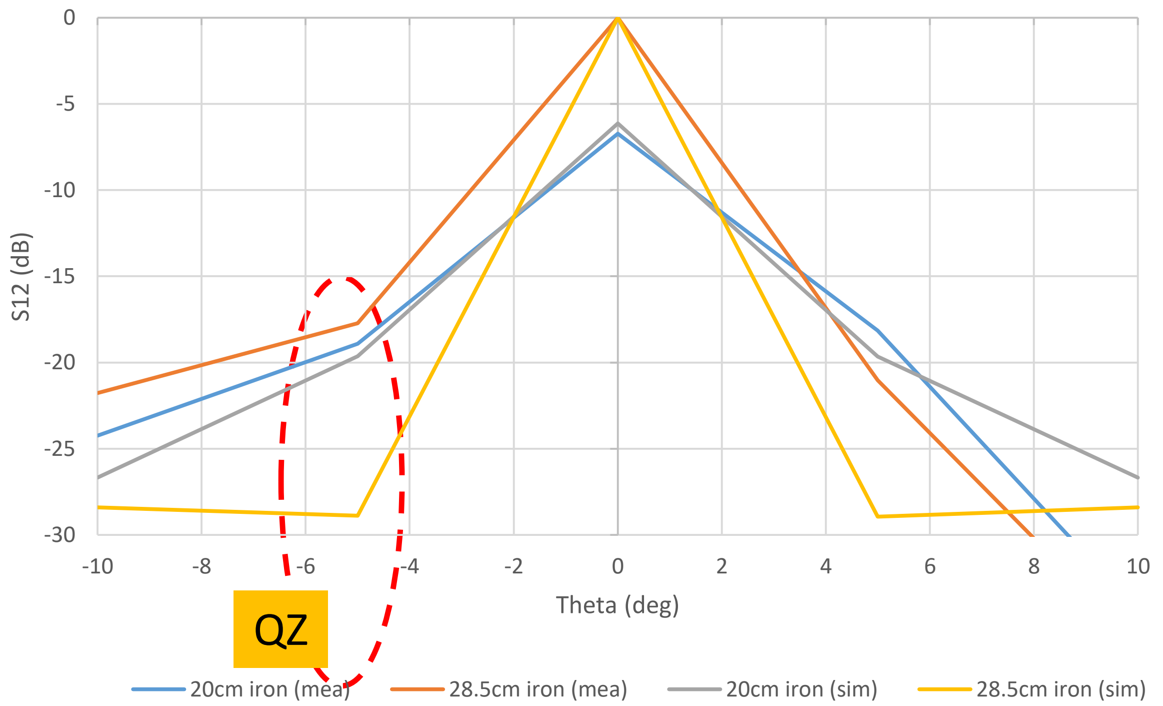
量測結果

	RCS計算值	RCS模擬值
28.5cm iron	21.1 dBsm	21 dBsm
20cm iron	15 dBsm	14.9 dBsm

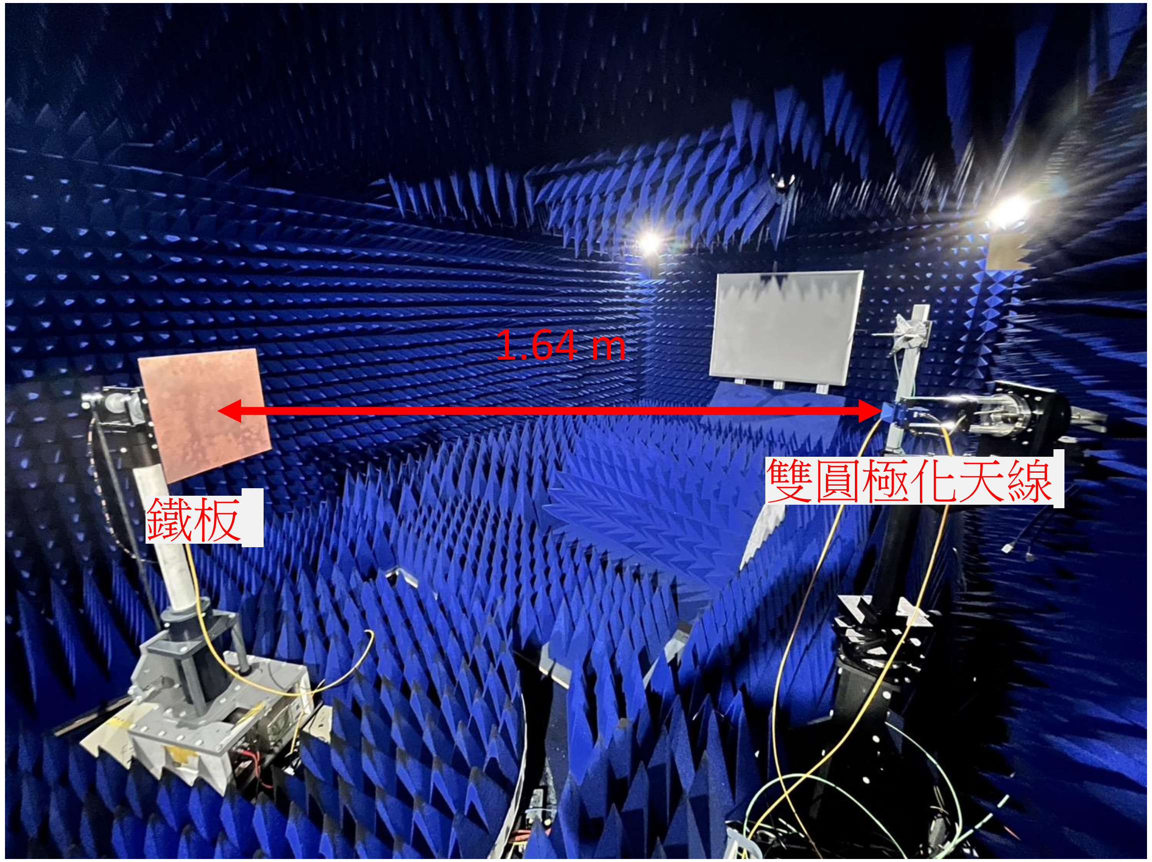
$$\sigma(\text{dBsm}) = 10\log_{10}[\sigma(m^2)]$$

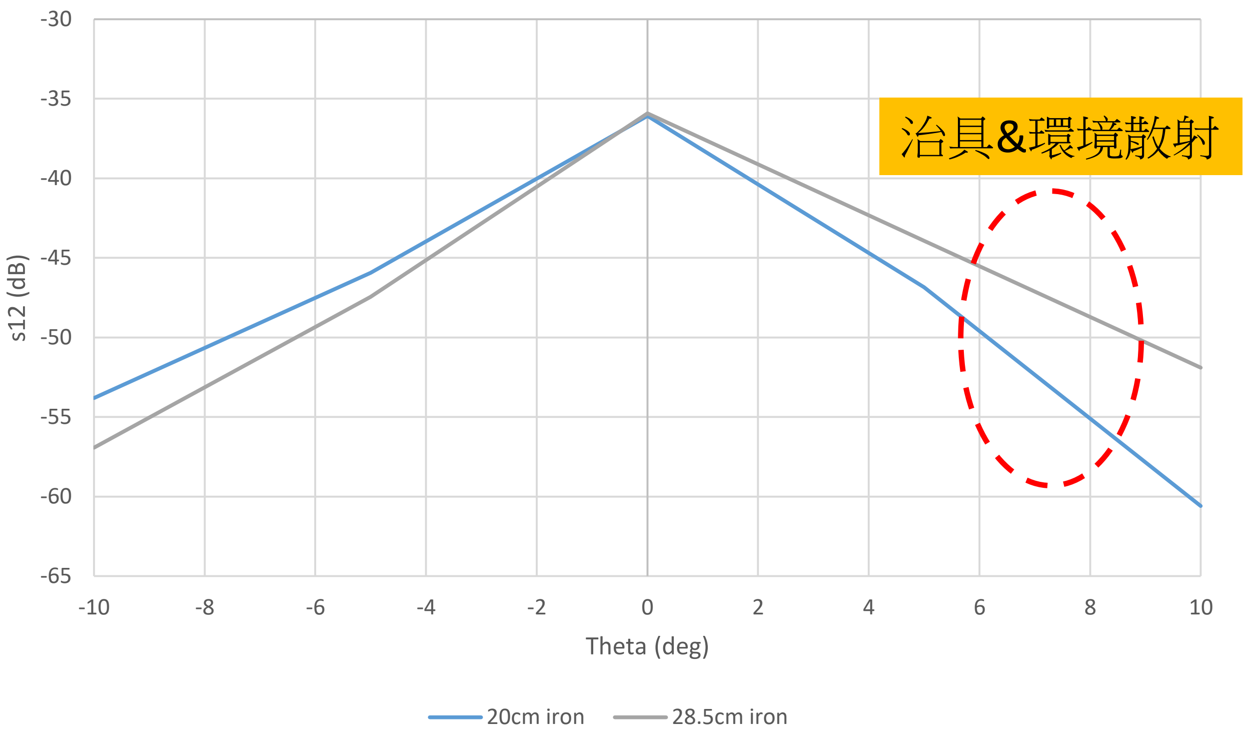


正規化後數值比較



直接遠場??





QZ不足：
20 cm 鐵板、 28.5 cm 鐵板量測結果相近

大綱

- RIS及OTA量測重要參數介紹
- RIS OTA量測文獻分享
- RIS OTA量測系統介紹
- 結論

川升股份有限公司

結論 – RIS OTA

- ✓ RIS OTA挑戰：
  ➔ Bistatic、Path loss校正、AoA/AoD有效角度、散射
- ✓ CATR Tx + NF Rx ➔ Bistatic
- ✓ 替代法 ➔ 解決path loss校正
- ✓ 轉台調整入射角度+機械手臂 ➔ 提高AoA/AoD有效角度
- ✓ 雙圓極化+time gating ➔ 解決AoA=AoD
- ✓ Baffle ➔ 解決散射問題

R&S

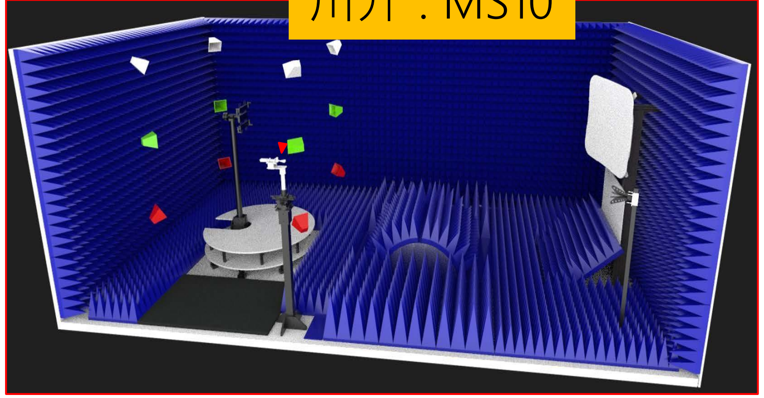
SMW200A

FSW

ZNA

\+

川升 : MS10



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戰略夥伴II ： 正于微波股份有限公司
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(臨廣科技產業園區)