高速數位電路與無線通訊系統之電磁相容技術發展與應用

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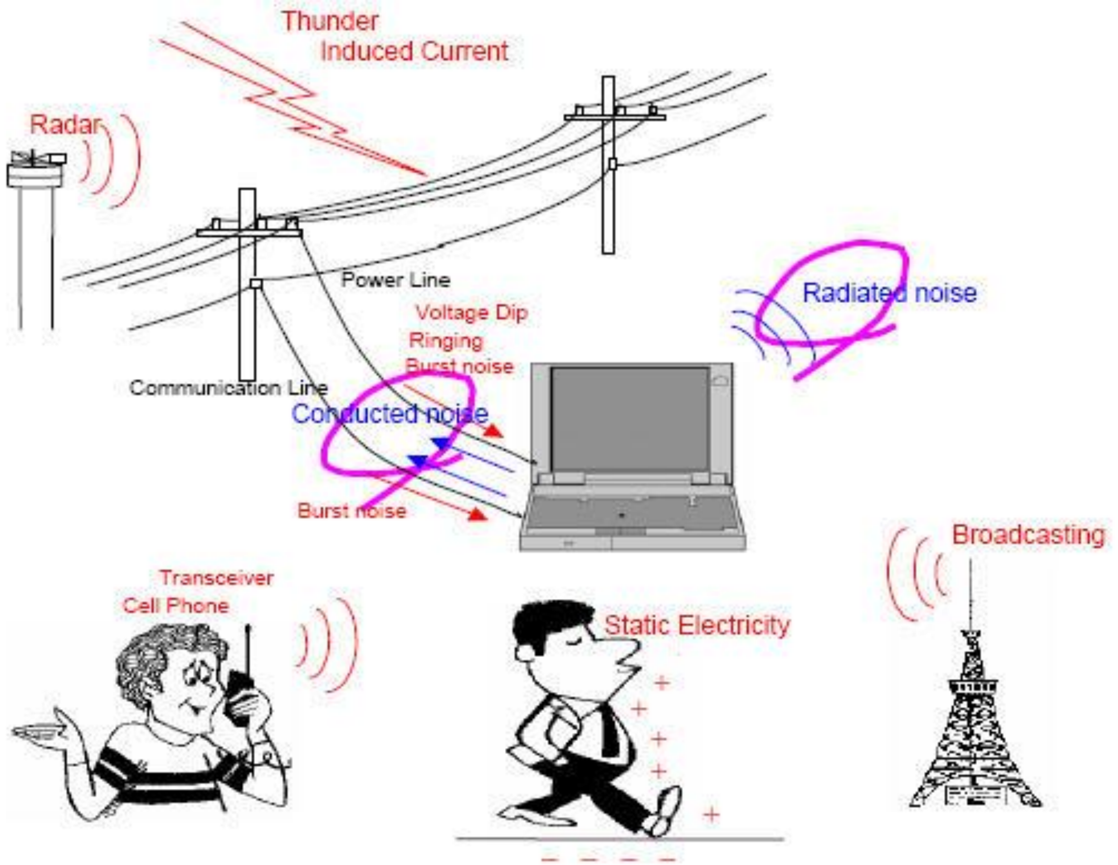
Outline

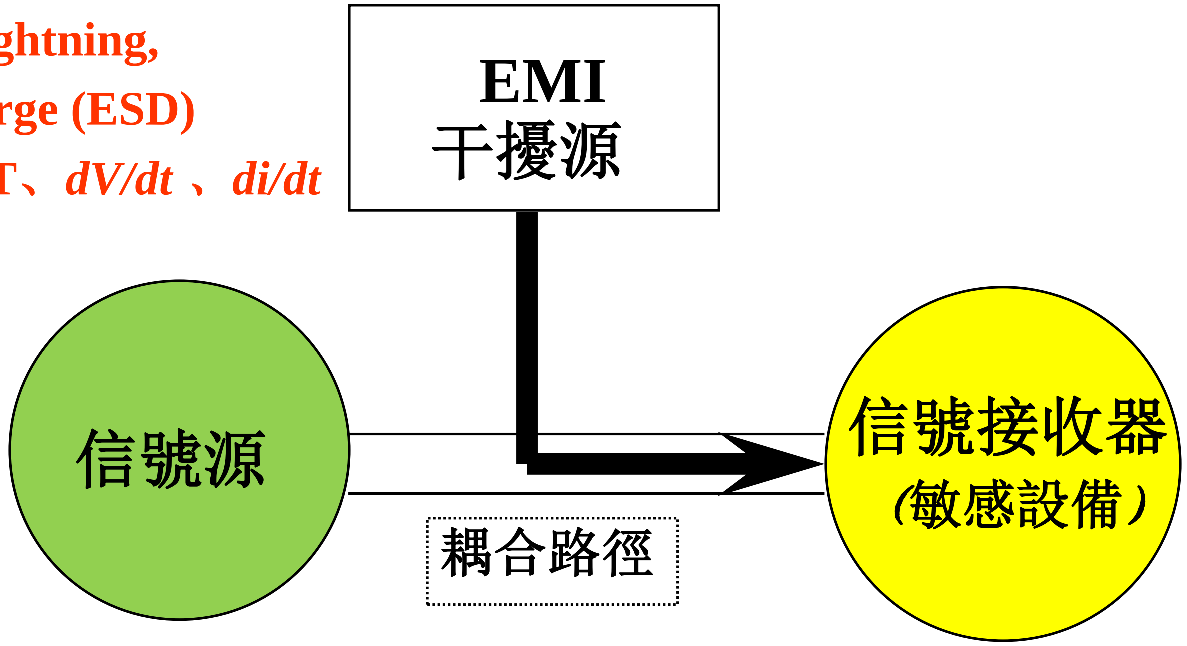
- Introduction to EMI and RFI for High-Speed Systems
- Trend of Wireless Communications and Automotive Development
- Platform Noise Impact on Throughput
- EMI Analysis of Key Components in Mobile Device
- Application of Noise Budget and Analysis Model for System Integration
- Conclusion

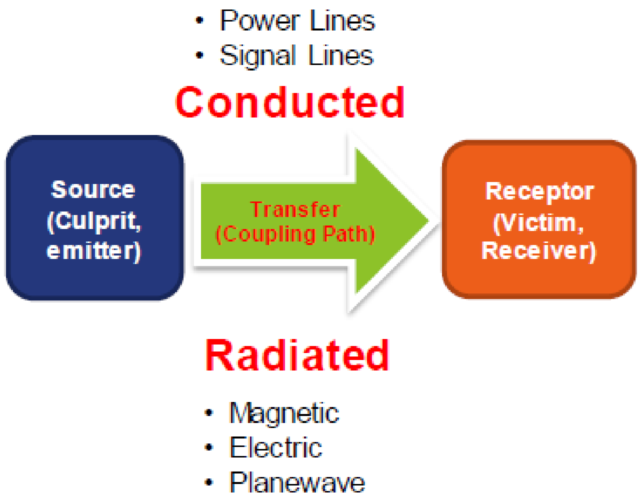
What is EMI and EMC?

–**Natural Sources: Lightning, Electrostatic Discharge (ESD)**

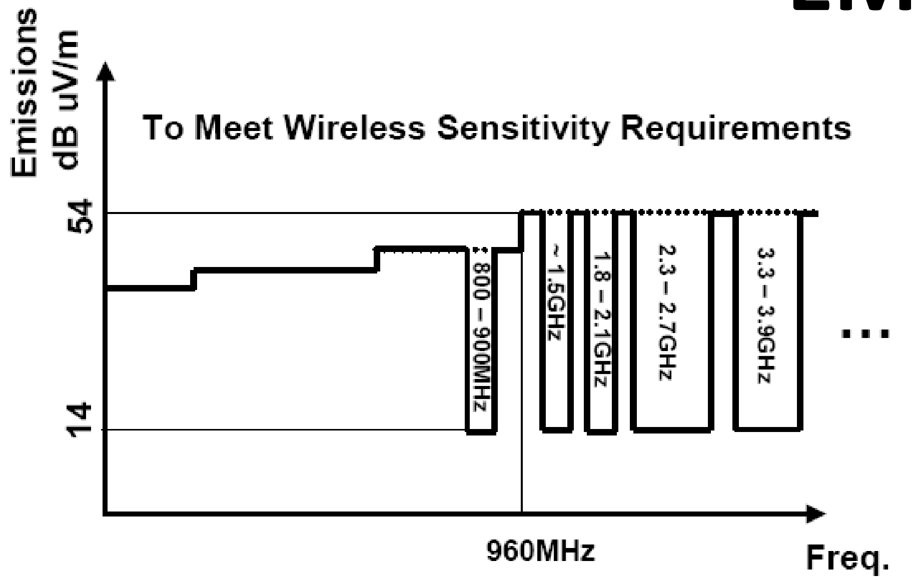
- **Artificial Noise: EFT、*dV/dt* 、*di/dt***







EMI vs. RF Interference



- EMI Limits:

@1MHz BW, 54dBuV/m = -53dBm @3m

= -33dBm @3cm

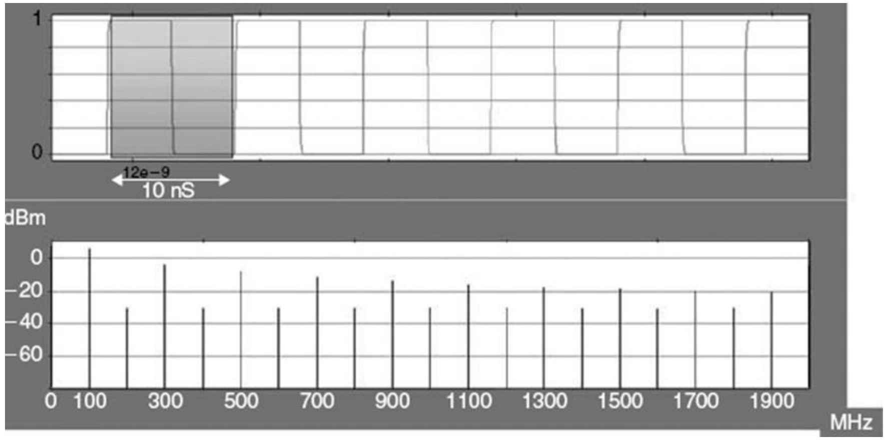
Calculations:

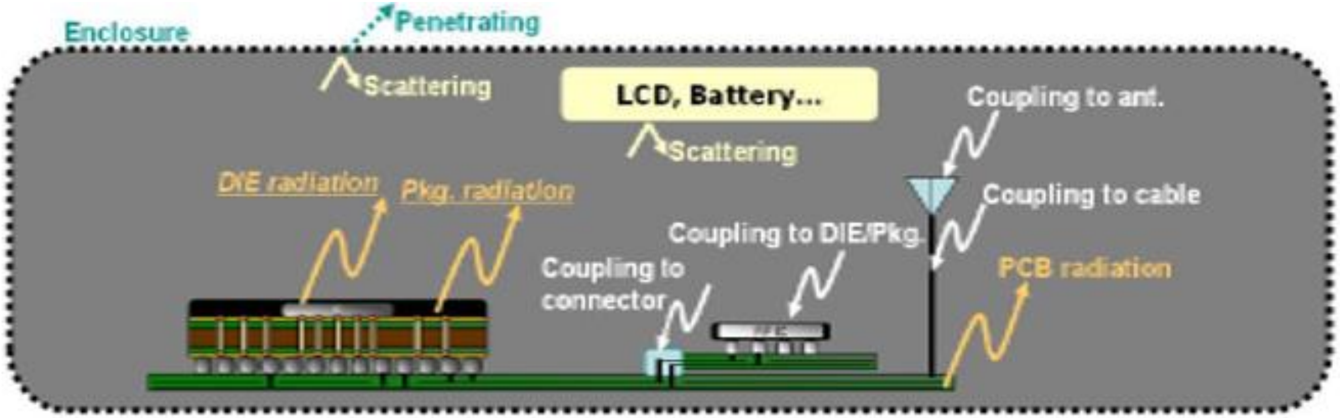
- Wireless Sensitivity Requirements:

-86dBm @20MHz = ~-73dBm @1MHz (10log(20/1))

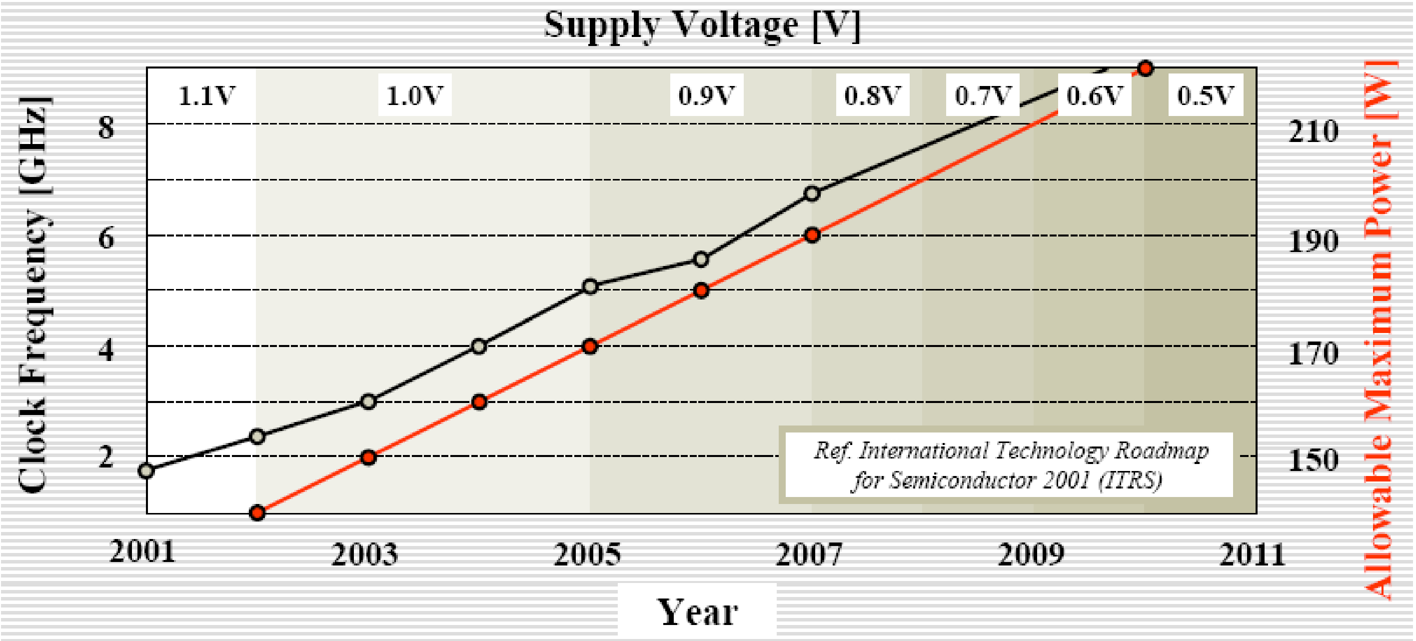
(802.11@11Mbps)

40dB difference!

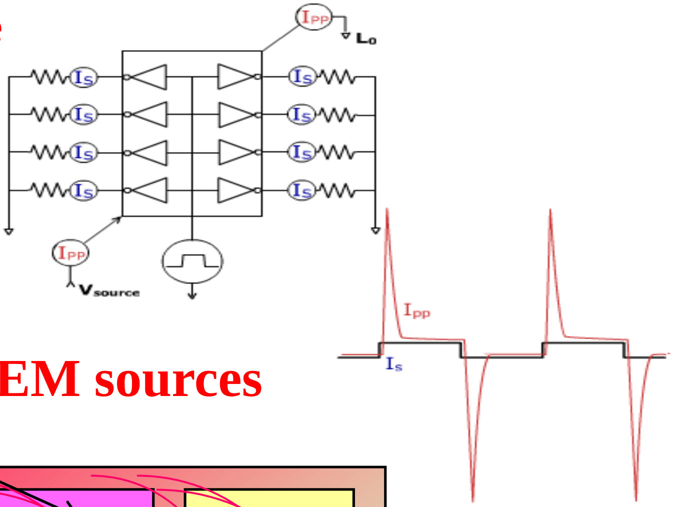




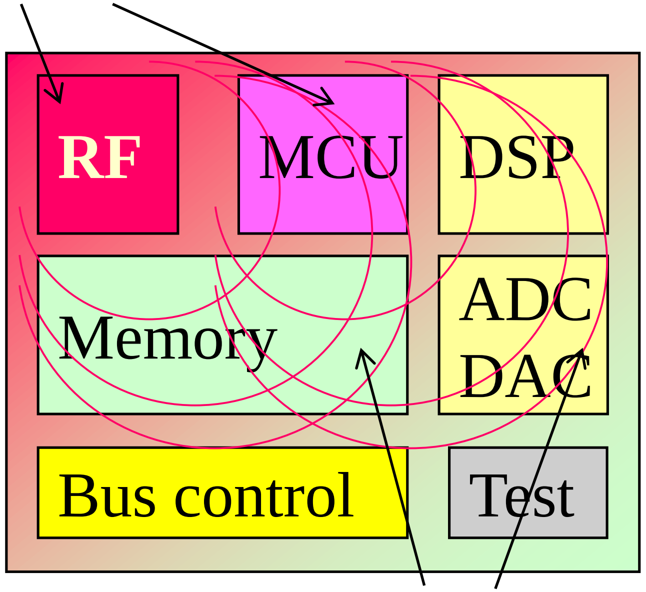
High Speed Digital System Trends



More complex designs, more power on chip, and more susceptible



Most powerful EM sources

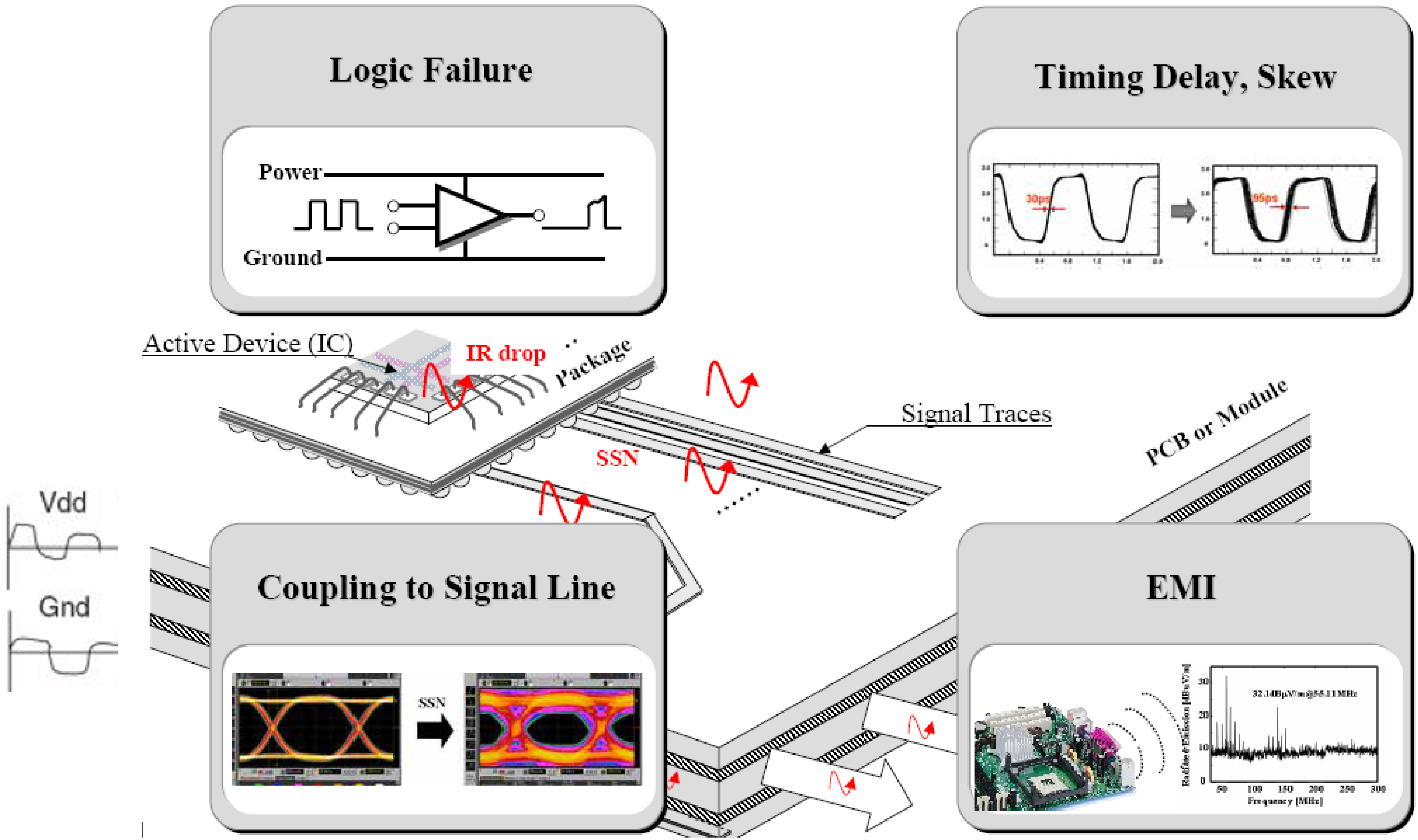


Most susceptible parts

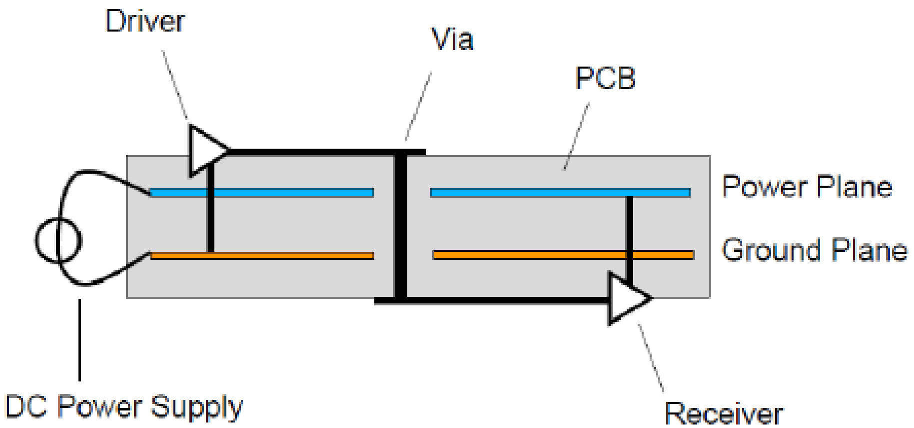
- **Faster Speed(Rise Time)**
- **Bigger Power Consumption**
- **Higher PCB Density**
- **Increasing Complexity**

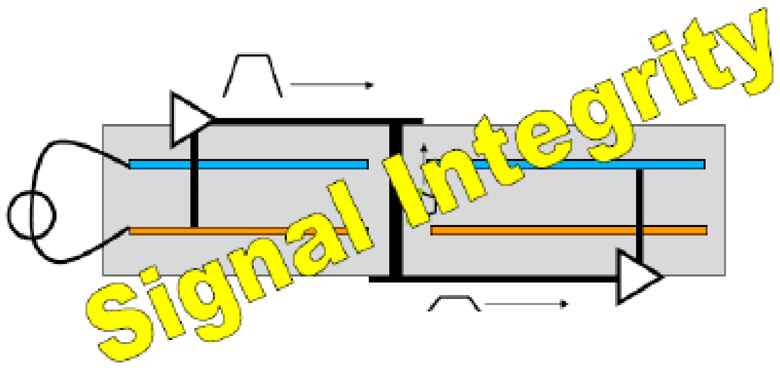
- **Timing Margin**
- **Signal Integrity**
- **Power Integrity**
- **EMI**

Problems by Power/Ground Noise



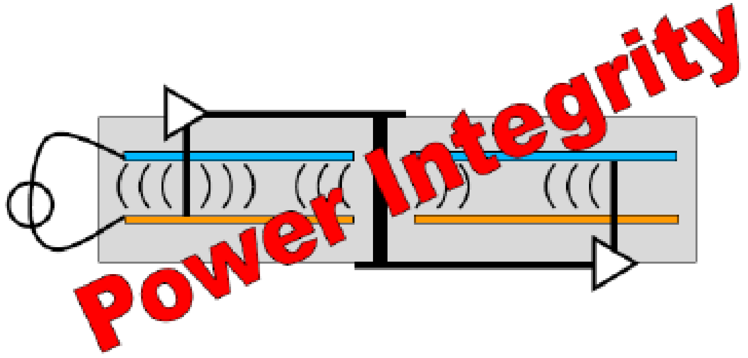
Challenges in High Speed Digital Design





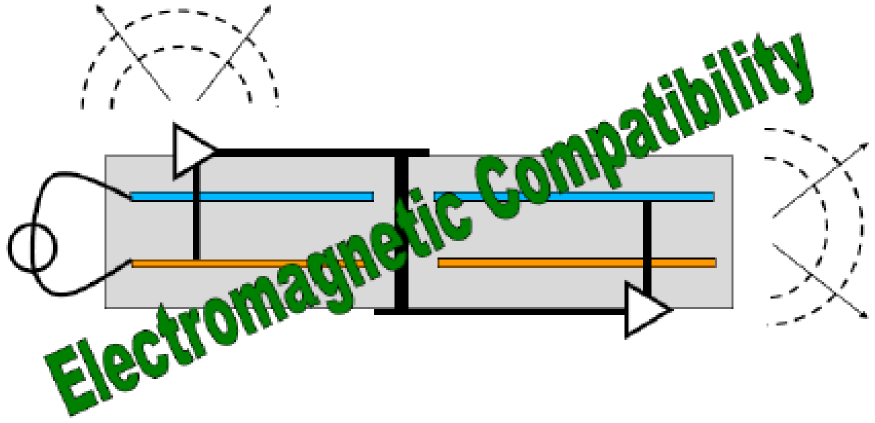
Signal Transmission Issues:

Attenuation, Reflection, Dispersion, Interference, Crosstalk



Power Delivery Issues:

Voltage Drop, Switching Noise, Crosstalk



Electromagnetic Compatibility Issues:

Near Field Coupling, Radiated Emissions

Triangle of EMC related Issues

EMC

- Normal Mode Radiation
- Common Mode Radiation
- Interference

SI (Signal Integrity)

- Delay/Timing Control
- Reflection Noise
- Crosstalk Noise
- Eye Opening Jitter

PI (Power Integrity)

- PWR/GND Plane Resonance
- SSN
- PWR Supply Impedance
- Decoupling

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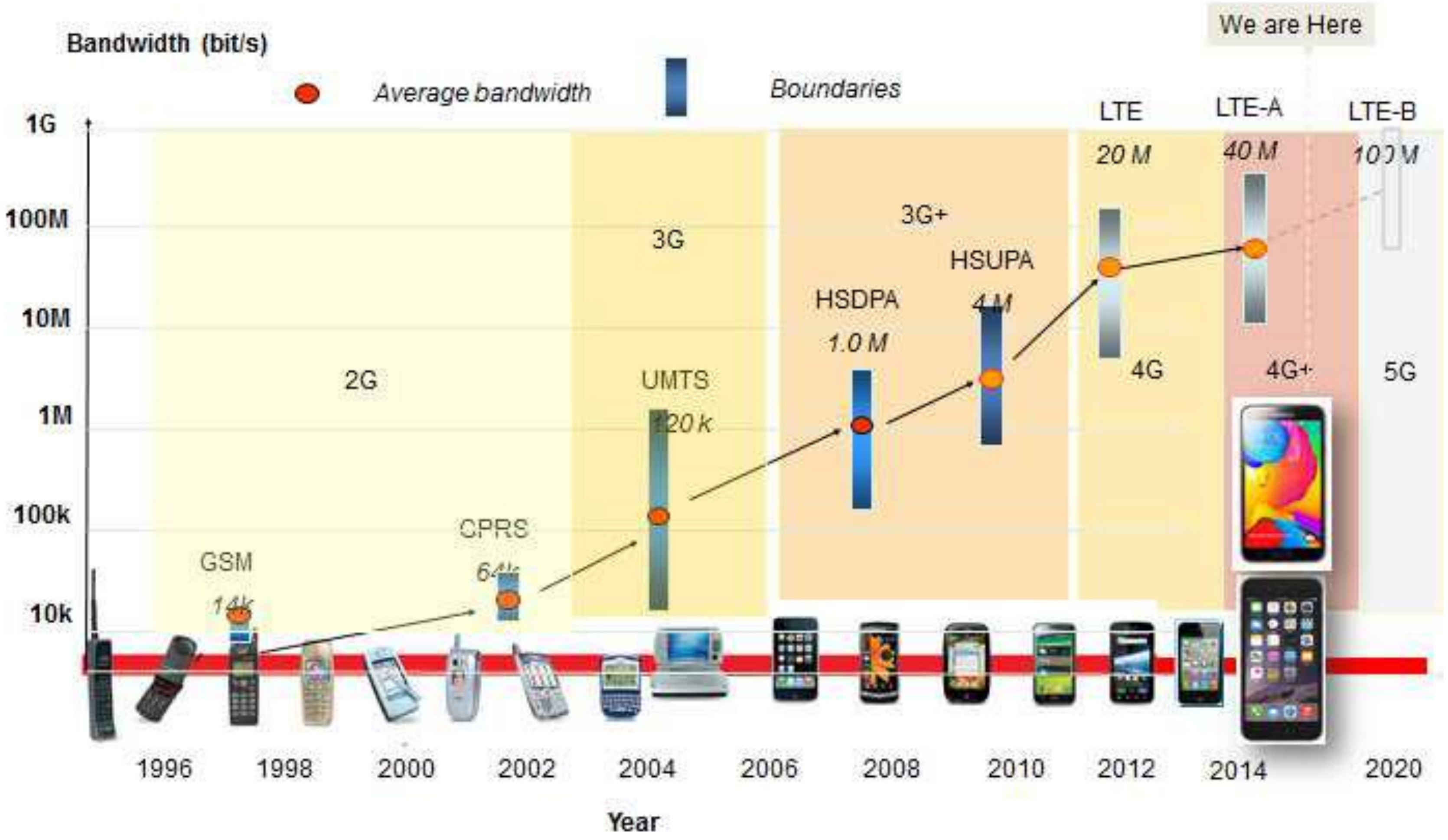
The mobile communication and trend toward higher data bandwidth



Evolution of Wireless Devices

RF SAR OTA TP

?

- Applications Innovation
- IP-LBS-HD Resolution, ….

1G

analog voice communication

2G

digital services

2.5G

quicker data access (384kbps)

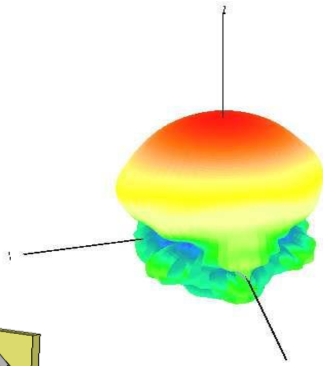
3G

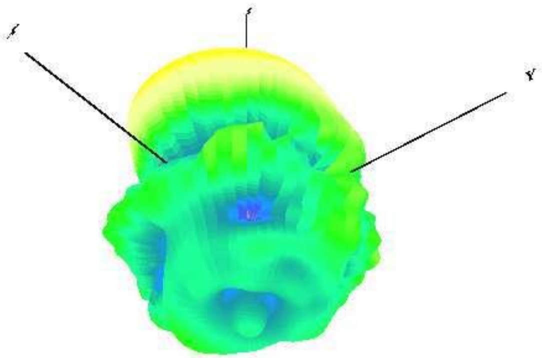
higher speed connectivity (2Mbps)

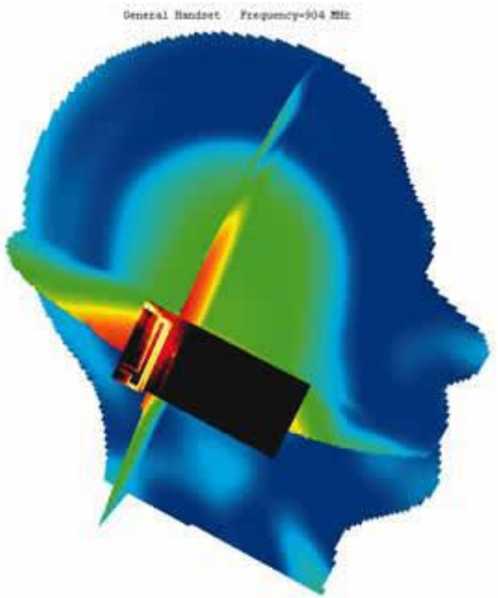
4G-5G

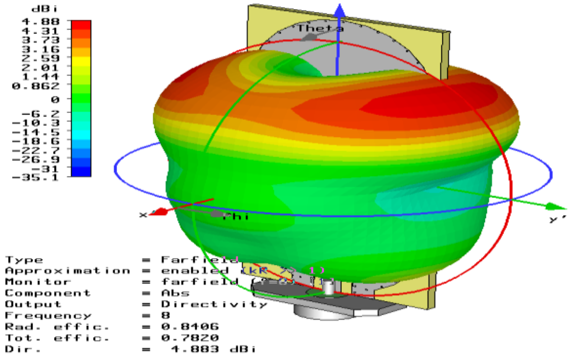
high speed Broadband (>20Mbps)

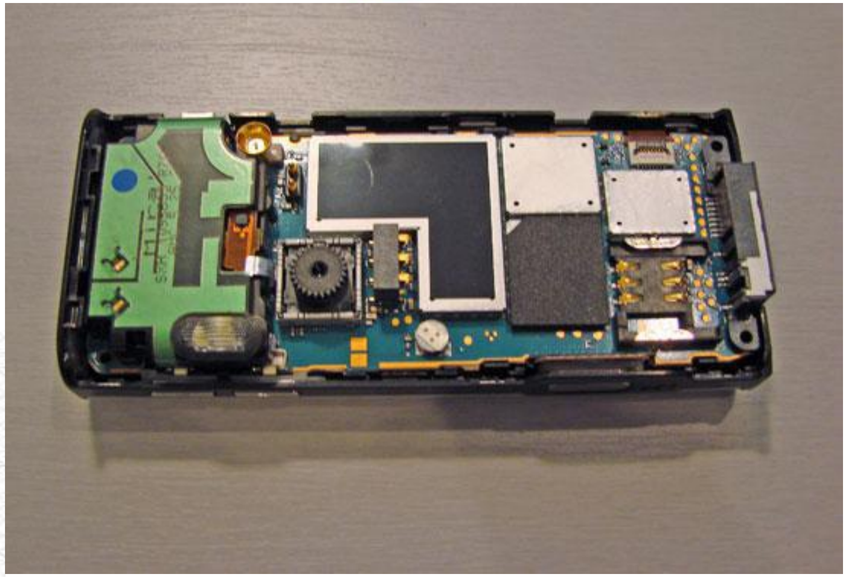
Antenna Near Field and Far Field

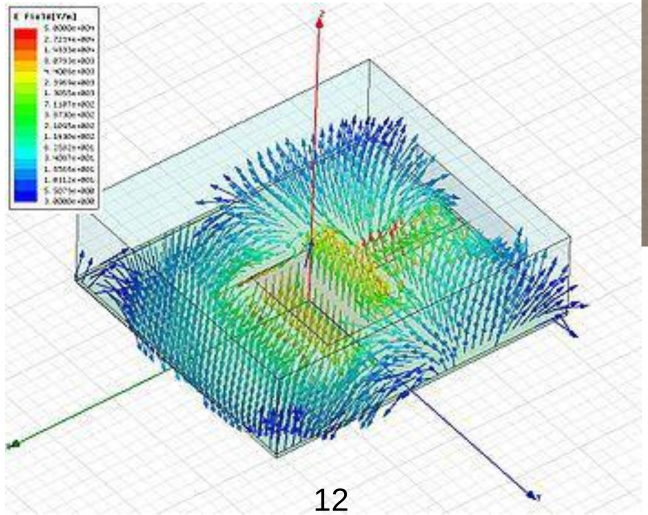


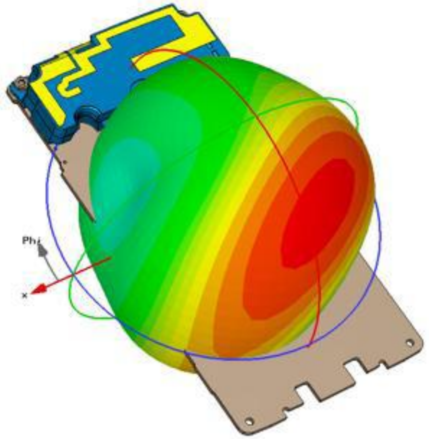


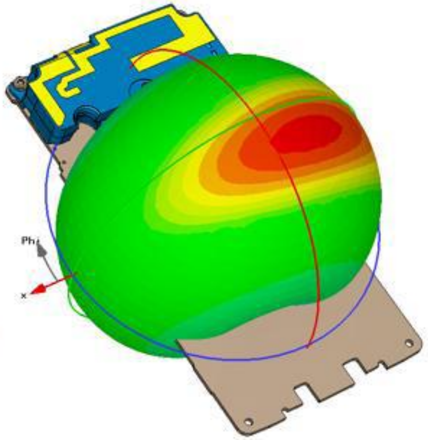












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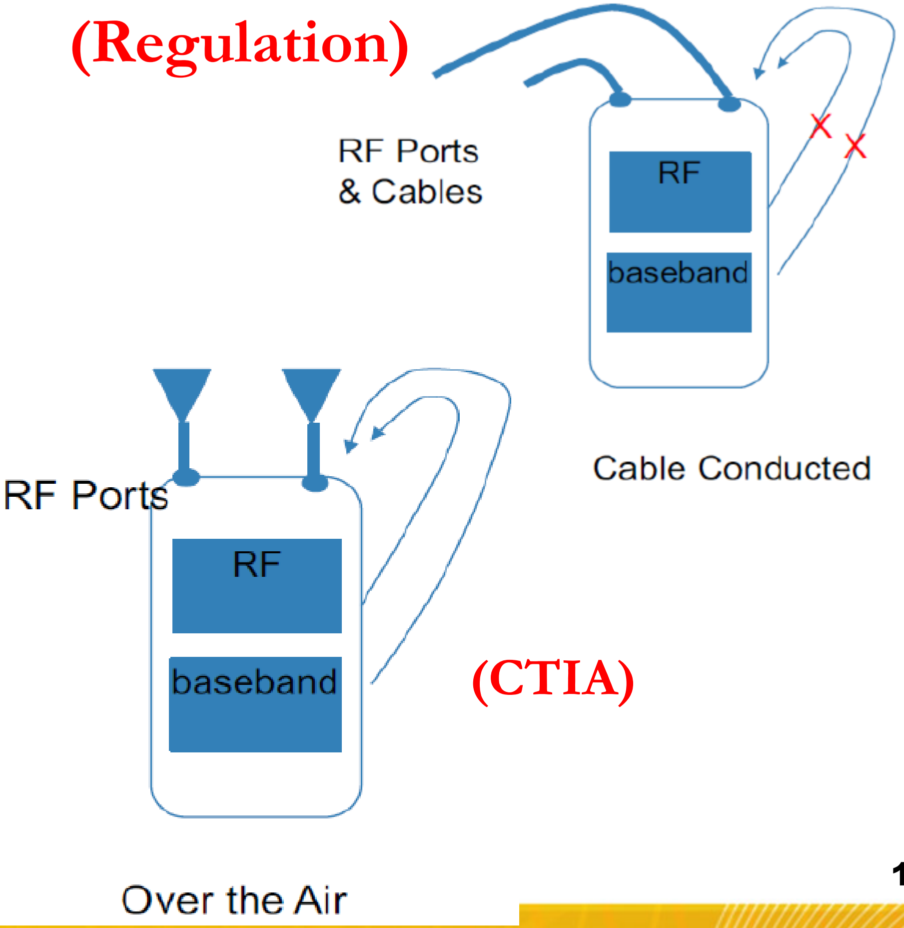
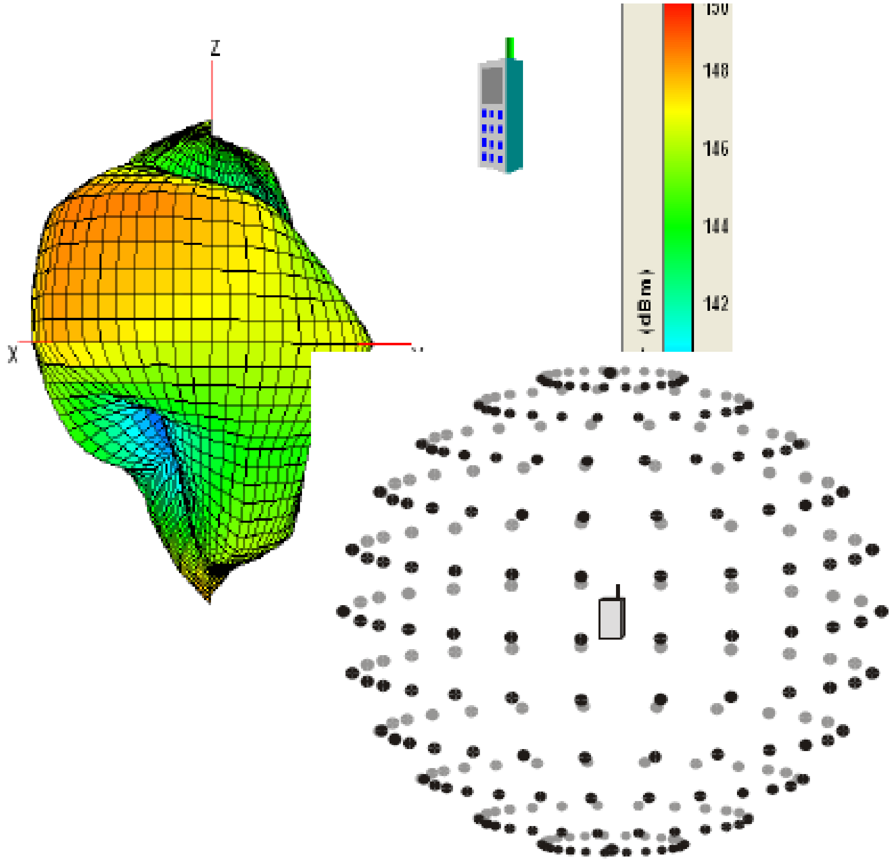
What's the OTA Measurement?

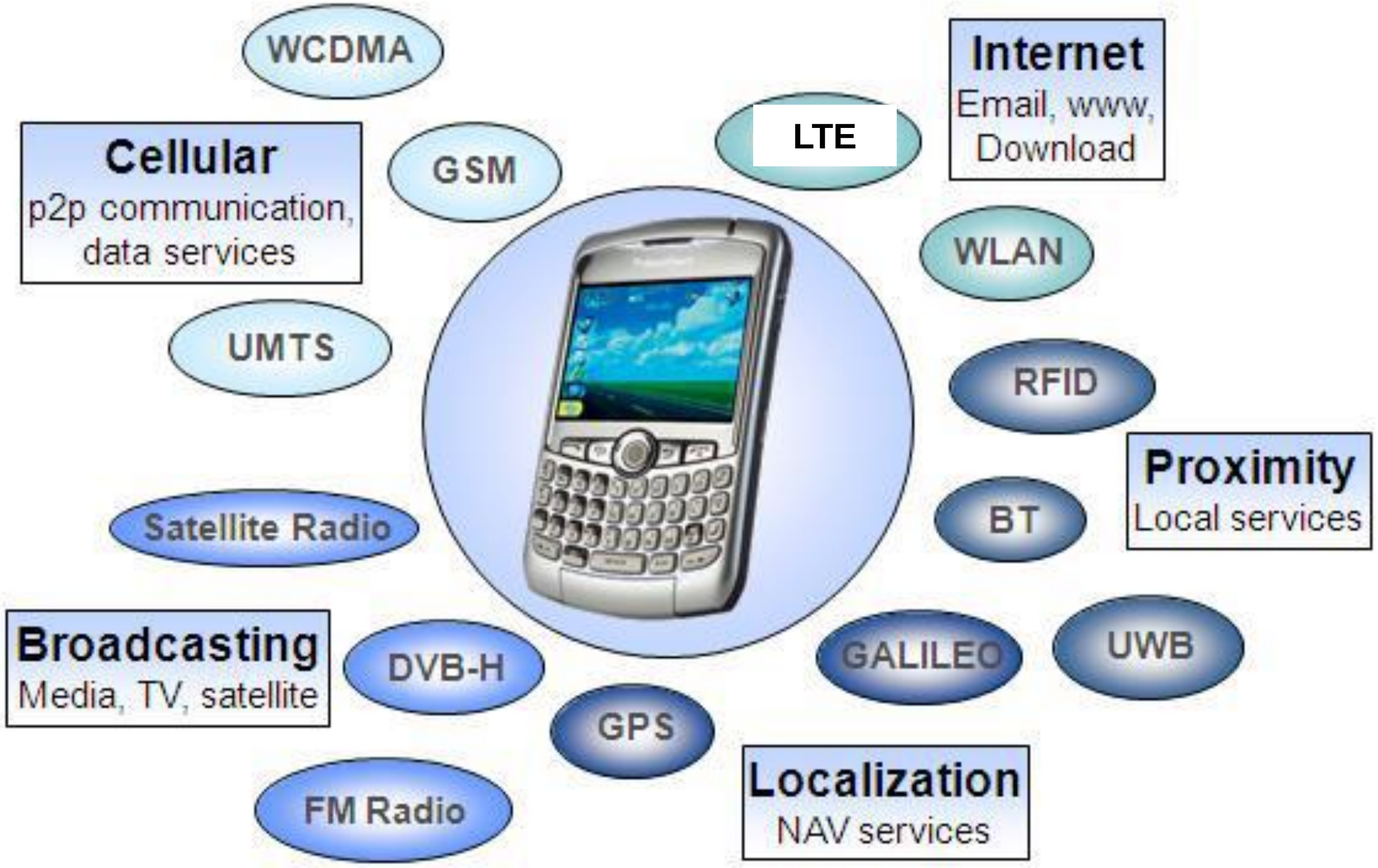
OTA: Over-the-Air

The purpose is to measure the 3-dimensions (X, Y, Z) antenna pattern for transmit power and receiver sensitivity for wireless devices.



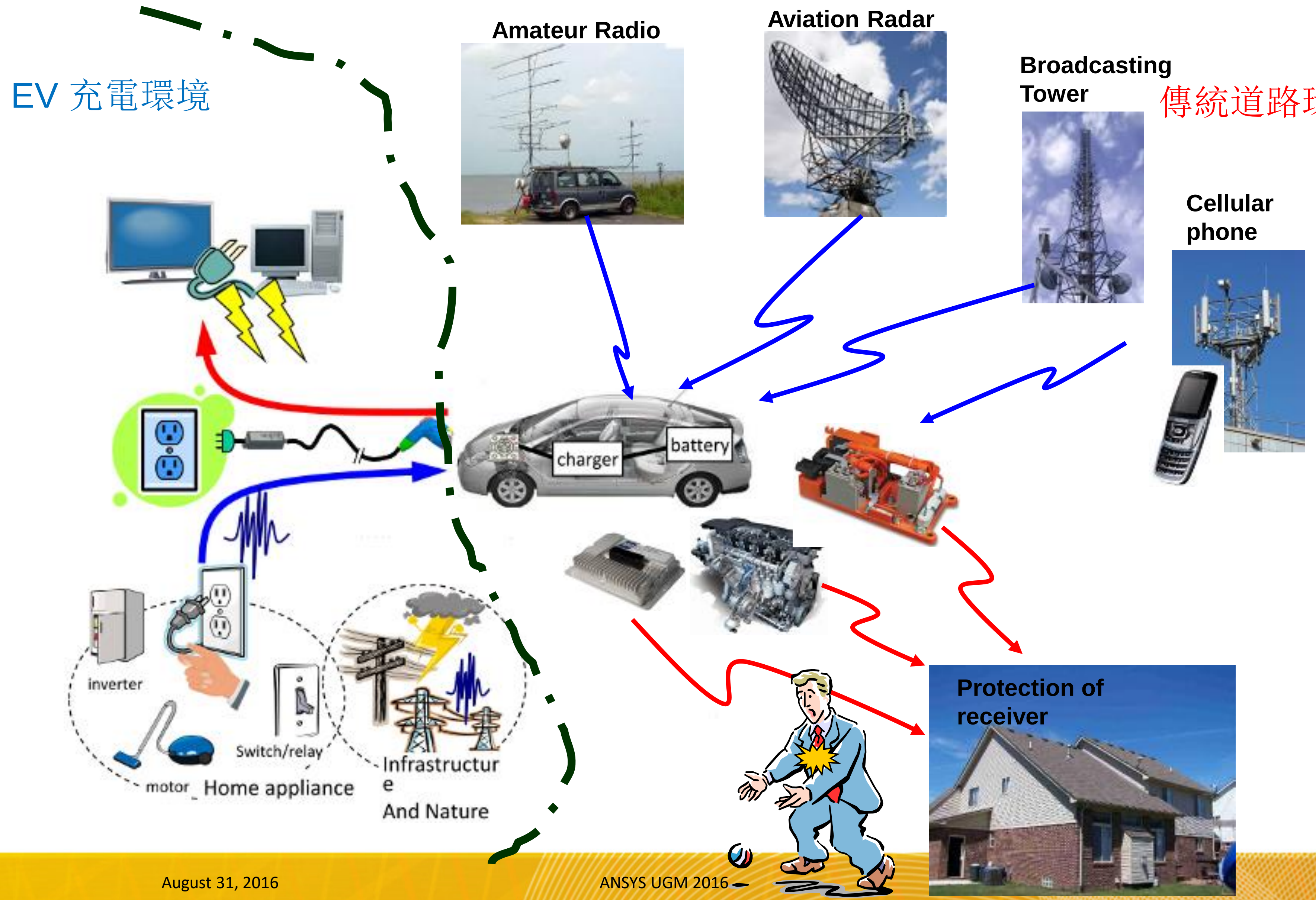


What is On-Board Self Jamming?



Lots of on-board antennas/wireless modules in Modern Mobile Phone !!

車輛EMC環境



EV 充電環境
Amateur Radio
Aviation Radar
Broadcasting
Tower
傳統道路環境
Cellular
phone
charger
battery
inverter
Switch/relay
motor
Home appliance
Infrastructur
e
And Nature
Protection of
receiver

Advanced Driver Assistance Systems (ADAS)

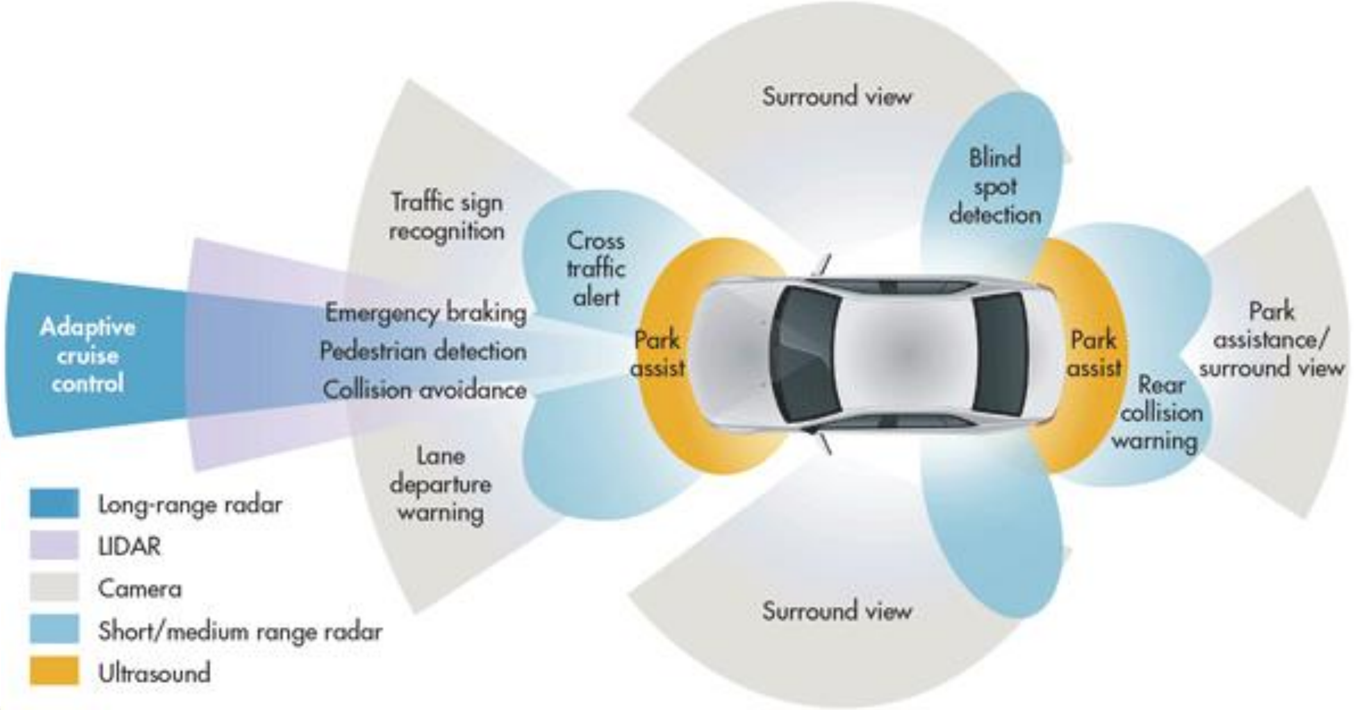
“Thing” = Vehicle (physical object)

Vehicle has multiple devices

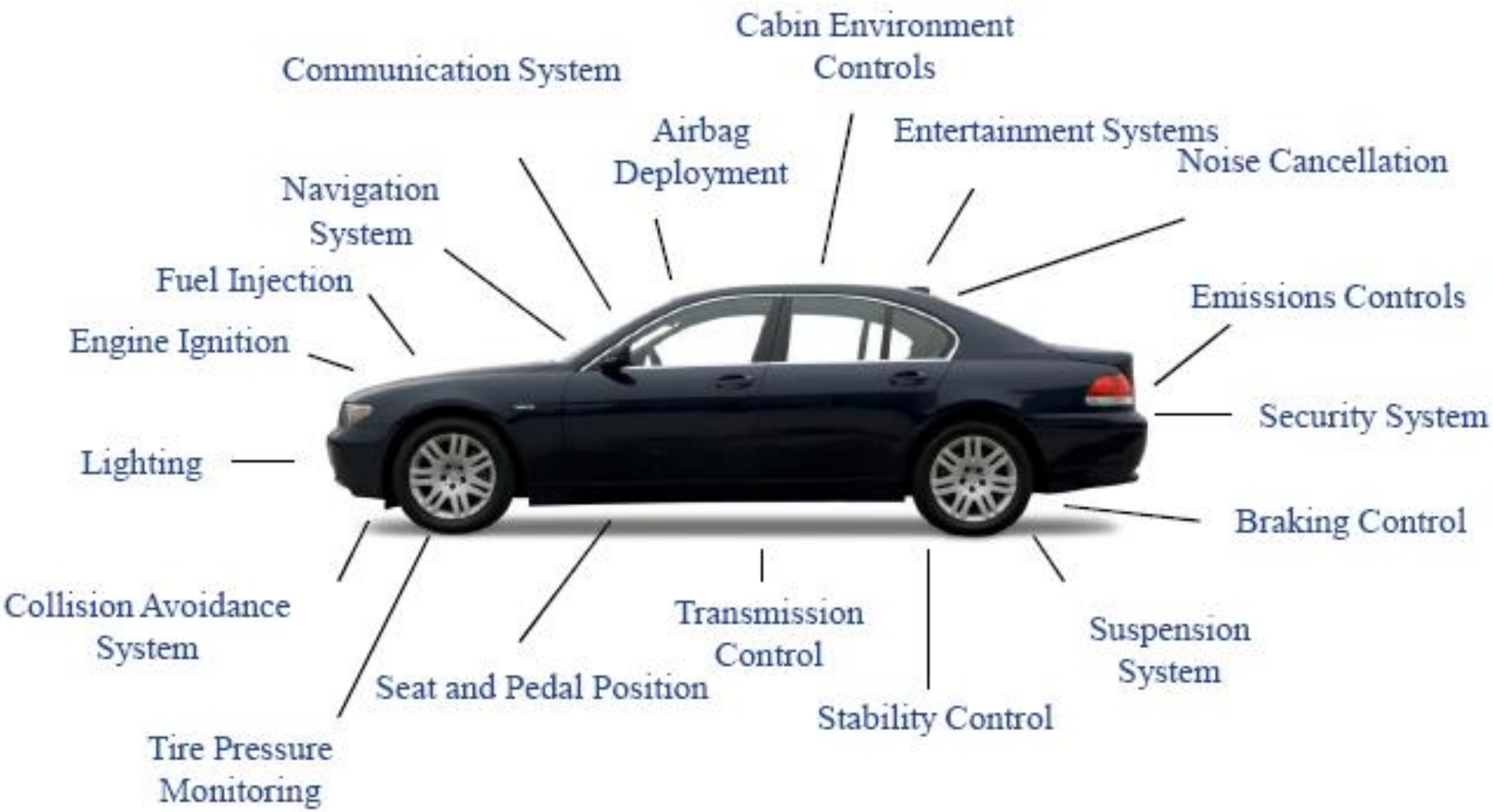
Sensors:
- GPS (location)
- Speed
- Suspension
- Skid
- Collision
- Air Bag
- Emission

Actuators:
- Brake controller
- Throttle controller
- Stability controller
- Windshield wiper

In IoT, all these devices (sensors and actuators) can be accessed via the Internet!



Complex Automobiles Electronic



當車輛使用電源線與AC電力網路連線進行充電時，則須符合AC電網EMC相關規範。

使用範圍多廣，須依政府法令規定。　　　　使用範圍多深，視車廠品質確保程度而定。

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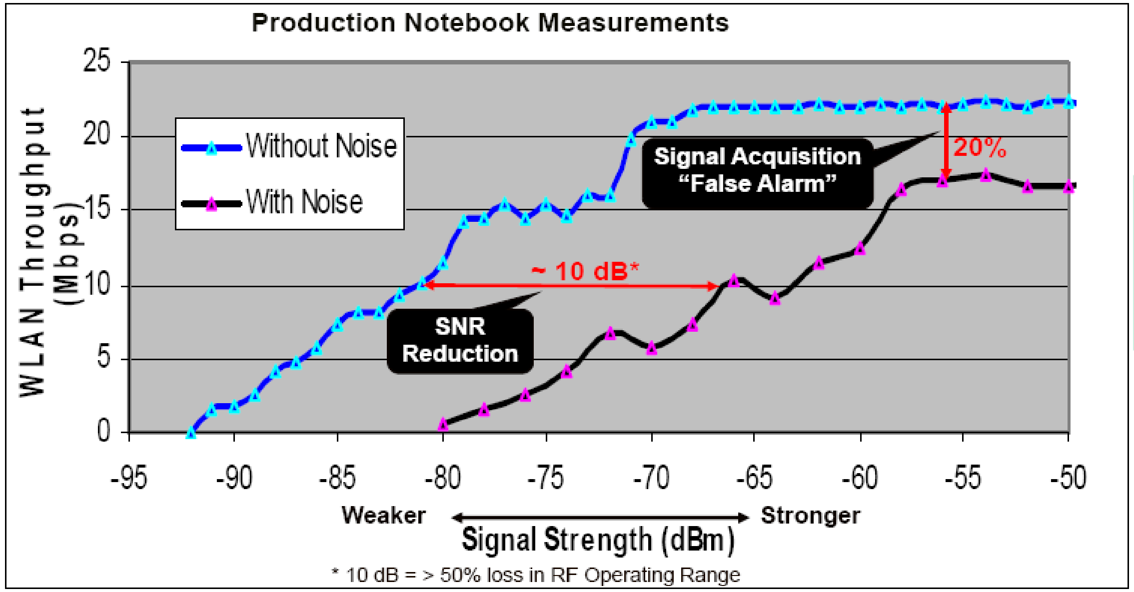
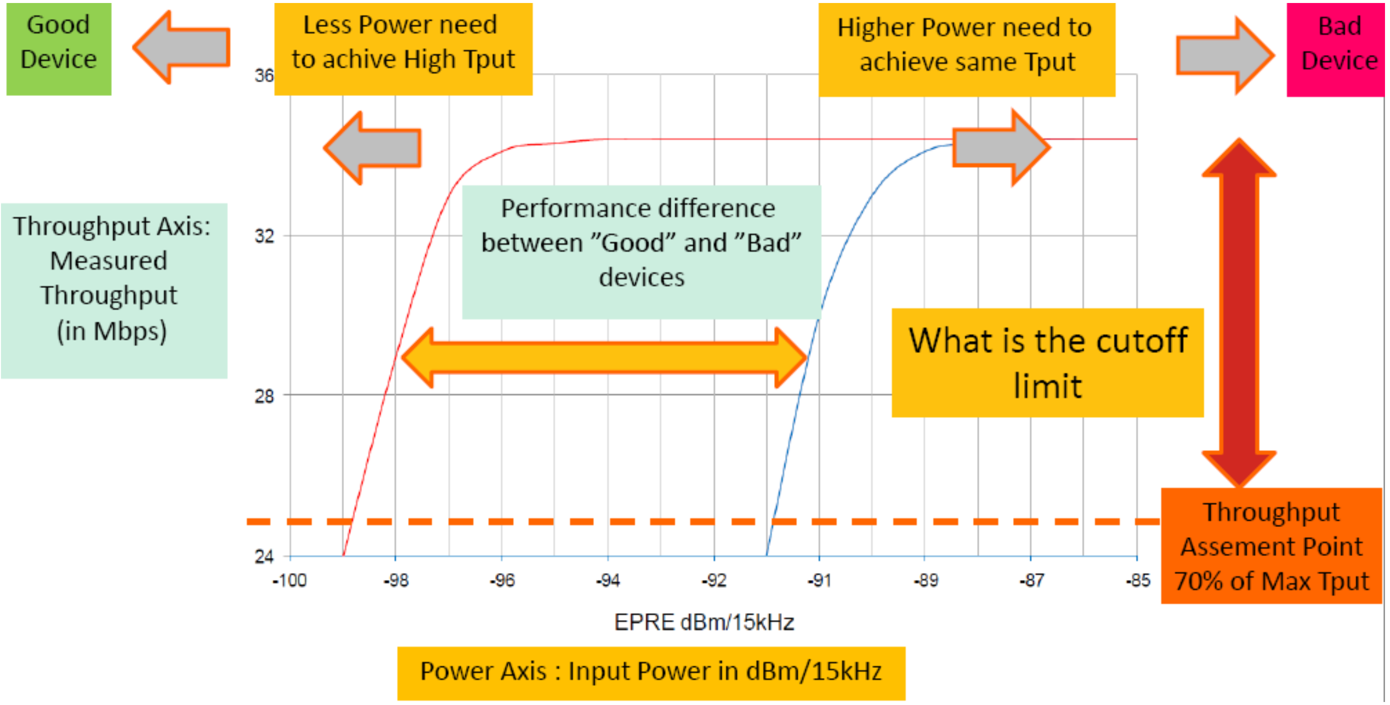
Figure of Merit for MIMO Systems - Throughput

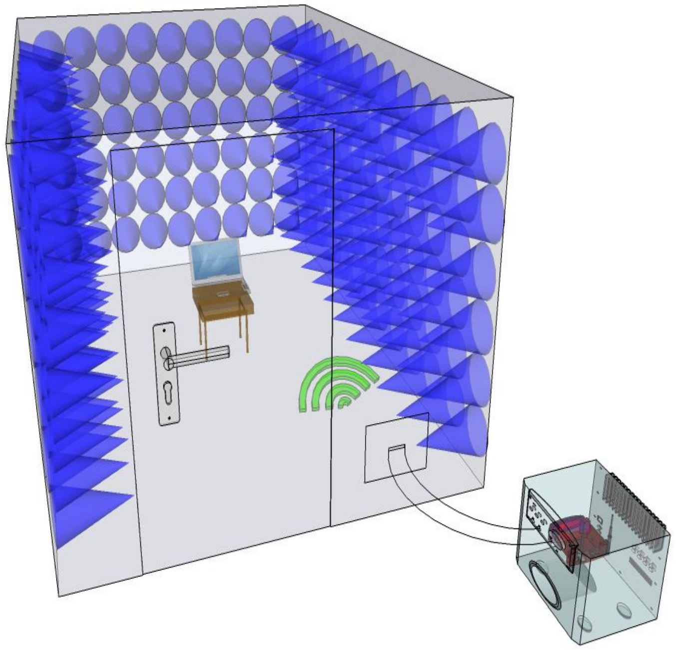


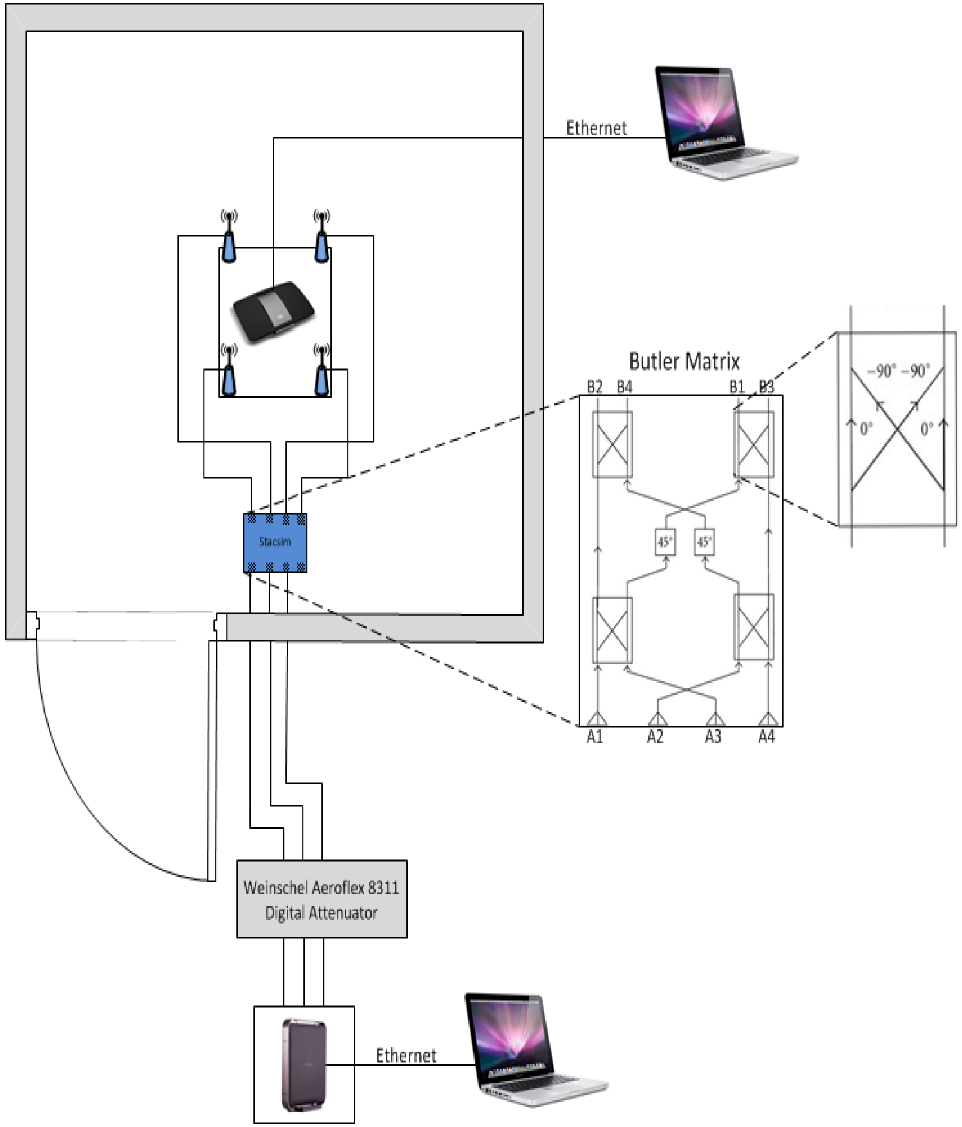


De-Sense represented by Noise PDF at different channel

Hybrid: OTA + Conduction

Full Anechoic RF Chamber with fixed multi-path & in-line programmable attenuation between the AP & DUT to simulate changing RF conditions

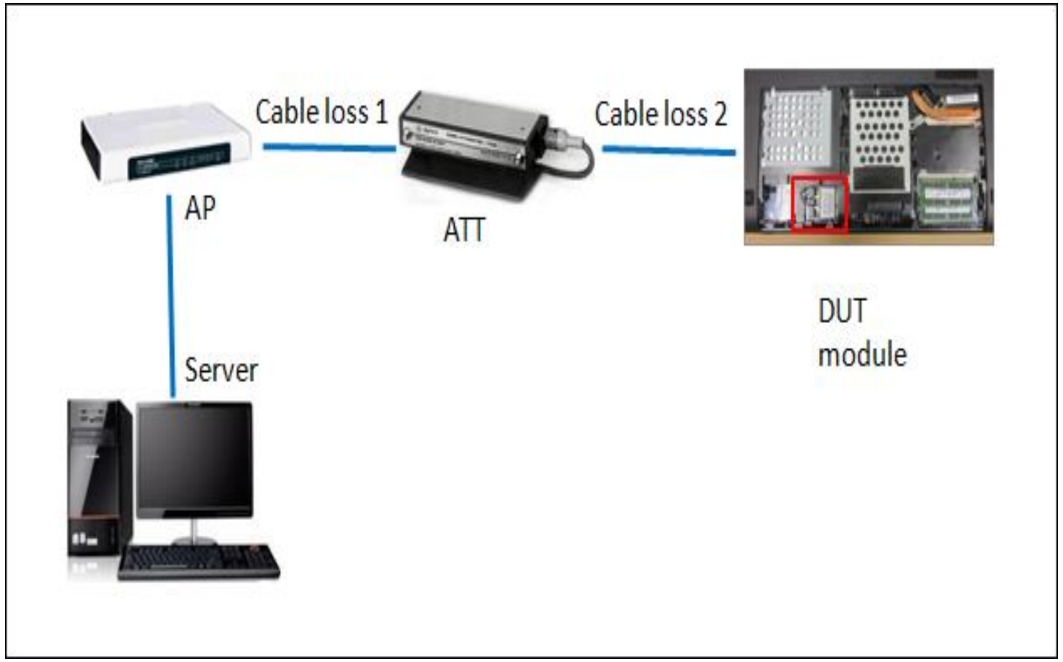




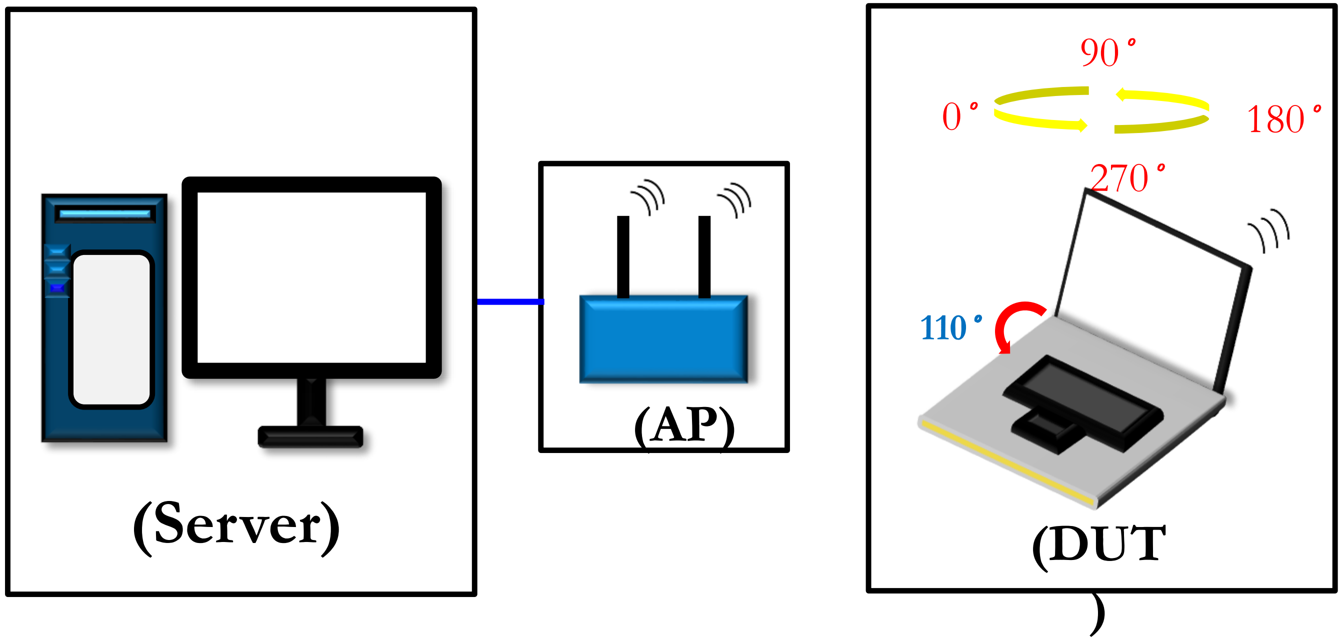
NOTE:

- A phase shifter (Butler matrix) is used to emulate multi-path
- Unless otherwise requested, channels used by default (Ch. 11 20MHz or Ch. 161 40MHz)
- Traffic type used by default (TCP)
- iperf commands:
  - ❑ Sender: iperf –c <IP_OF_SERVER> -w 256K –l 1470 –P4 –fm –i1 –t<DURATION>
  - ❑ Receiver: iperf –s –w 256K

Setup for Throughput Measurement



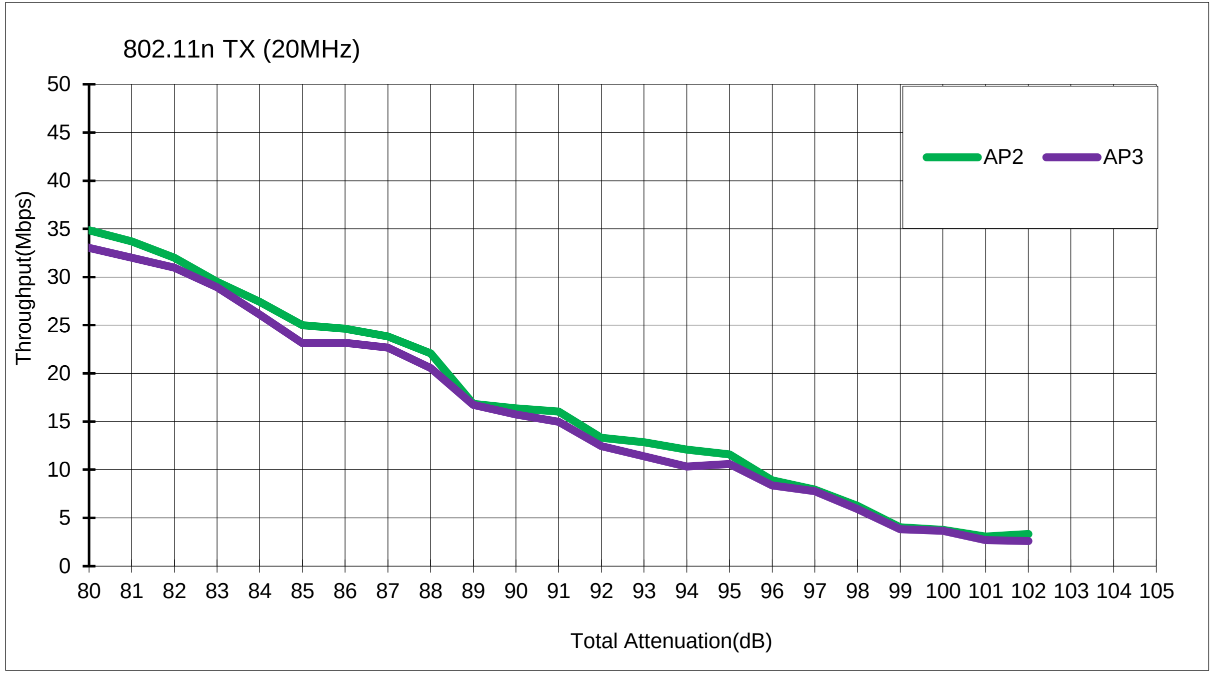
Conduction Test Setup



OTA Test Setup

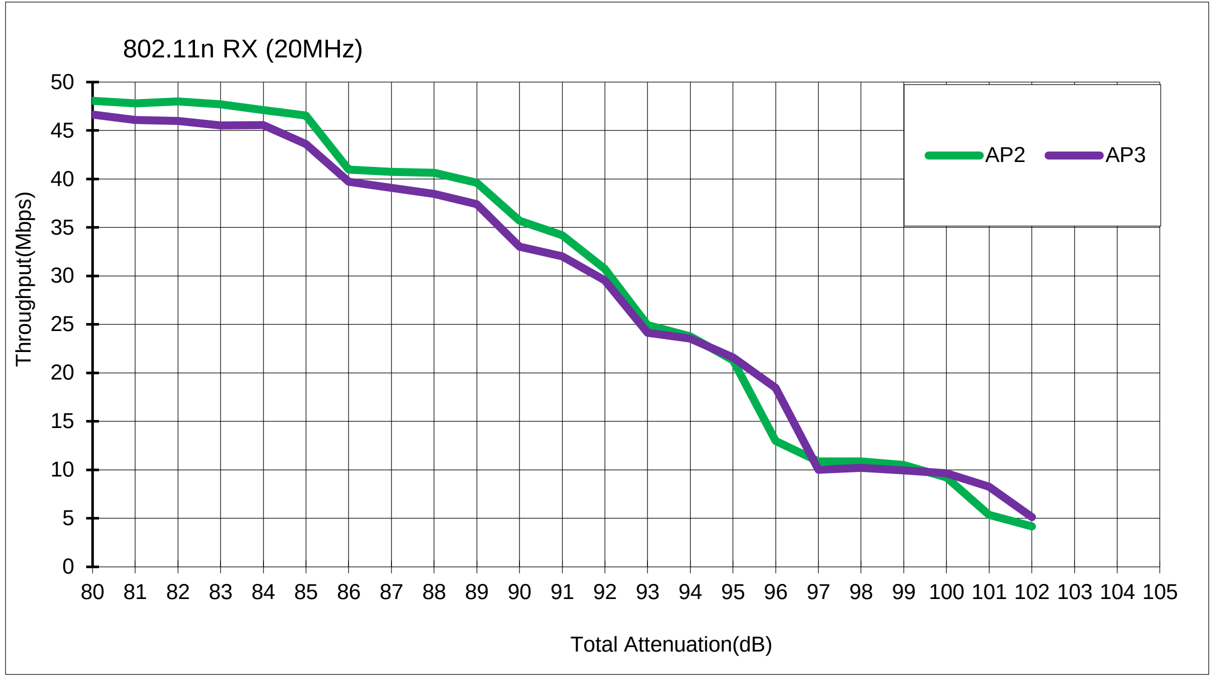
AP2 & AP3 - CH 01 (Tx mode)

CH01 TX			
Total Attenuation (dB)	AP2	AP3	AP2-AP3
65	45.917	43.845	2.072
75	43.155	41.696	1.459
80	34.856	33.046	1.81
81	33.7	32.002	1.698
82	32	30.988	1.012
83	29.504	28.943	0.561
84	27.425	26.088	1.337
85	24.995	23.125	1.87
86	24.624	23.16	1.464
87	23.849	22.675	1.174
88	22.066	20.542	1.524
89	16.825	16.738	0.087
90	16.372	15.74	0.632
91	16.05	14.972	1.078
92	13.297	12.457	0.84
93	12.852	11.382	1.47
94	12.098	10.323	1.775
95	11.576	10.581	0.995
96	8.886	8.372	0.514
97	7.925	7.773	0.152
98	6.227	5.92	0.307
99	4.012	3.822	0.19
100	3.769	3.646	0.123
101	3.053	2.692	0.361
102	3.318	2.593	0.725



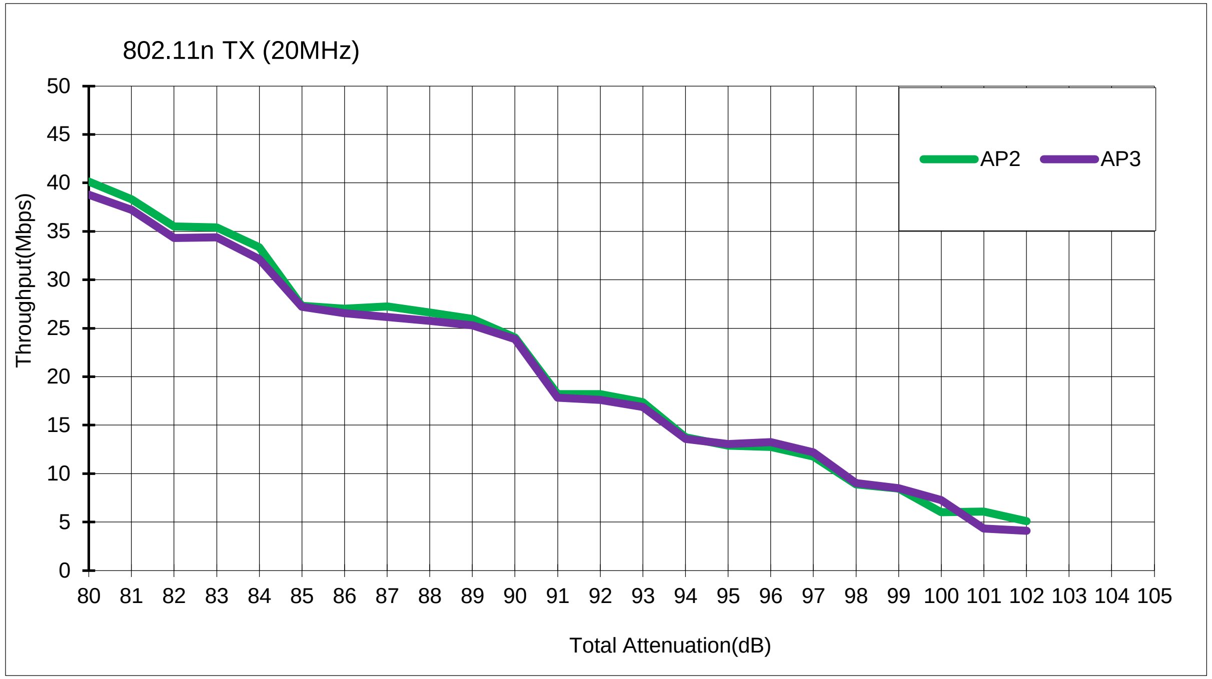
AP2 & AP3 - CH 01 (Rx mode)

CH01 RX			
Total Attenuation (dB)	AP2	AP3	AP2-AP3
65	48.553	46.819	1.734
75	48.001	46.313	1.688
80	48.056	46.627	1.429
81	47.79	46.086	1.704
82	47.996	45.981	2.015
83	47.693	45.518	2.175
84	47.091	45.537	1.554
85	46.53	43.602	2.928
86	40.975	39.725	1.25
87	40.734	39.088	1.646
88	40.621	38.451	2.17
89	39.618	37.405	2.213
90	35.693	32.995	2.698
91	34.186	32.02	2.166
92	30.728	29.553	1.175
93	24.941	24.144	0.797
94	23.761	23.539	0.222
95	21.282	21.594	-0.312
96	12.992	18.457	-5.465
97	10.859	10.002	0.857
98	10.87	10.192	0.678
99	10.505	9.949	0.556
100	9.206	9.633	-0.427
101	5.355	8.266	-2.911
102	4.179	5.116	-0.937



AP2 & AP3 - CH 06 (Tx mode)

CH06 TX			
Total Attenuation (dB)	AP2	AP3	AP2-AP3
65	46.28	44.1	2.18
75	45.396	44.24	1.156
80	40.114	38.77	1.344
81	38.327	37.211	1.116
82	35.503	34.326	1.177
83	35.417	34.386	1.031
84	33.354	32.139	1.215
85	27.311	27.212	0.099
86	27.012	26.541	0.471
87	27.246	26.155	1.091
88	26.637	25.758	0.879
89	25.957	25.31	0.647
90	24.051	23.889	0.162
91	18.193	17.837	0.356
92	18.202	17.617	0.585
93	17.363	16.89	0.473
94	13.733	13.565	0.168
95	12.897	13.035	-0.138
96	12.767	13.254	-0.487
97	11.763	12.177	-0.414
98	8.881	9.01	-0.129
99	8.445	8.484	-0.039
100	6.017	7.27	-1.253
101	6.067	4.338	1.729
102	5.091	4.095	0.996



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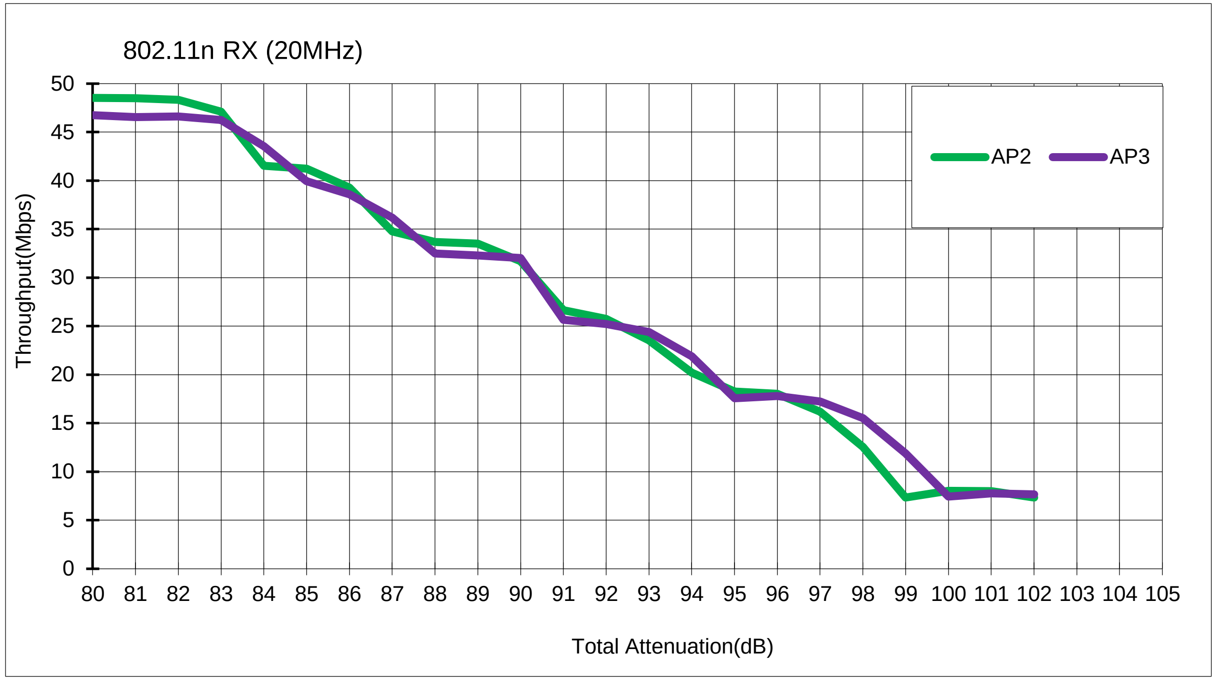
AP2 & AP3 - CH 06 (Rx mode)

CH06 RX			
Total Attenuation (dB)	AP2	AP3	AP2-AP3
65	48.435	46.889	1.546
75	48.236	46.672	1.564
80	48.537	46.743	1.794
81	48.492	46.533	1.959
82	48.313	46.598	1.715
83	47.106	46.256	0.85
84	41.521	43.528	-2.007
85	41.24	39.927	1.313
86	39.291	38.596	0.695
87	34.767	36.178	-1.411
88	33.665	32.498	1.167
89	33.517	32.284	1.233
90	31.687	32.018	-0.331
91	26.64	25.654	0.986
92	25.755	25.209	0.546
93	23.526	24.399	-0.873
94	20.19	21.883	-1.693
95	18.252	17.571	0.681
96	18.035	17.805	0.23
97	16.181	17.242	-1.061
98	12.558	15.511	-2.953
99	7.32	11.889	-4.569
100	8.012	7.44	0.572
101	8.008	7.759	0.249
102	7.326	7.673	-0.347



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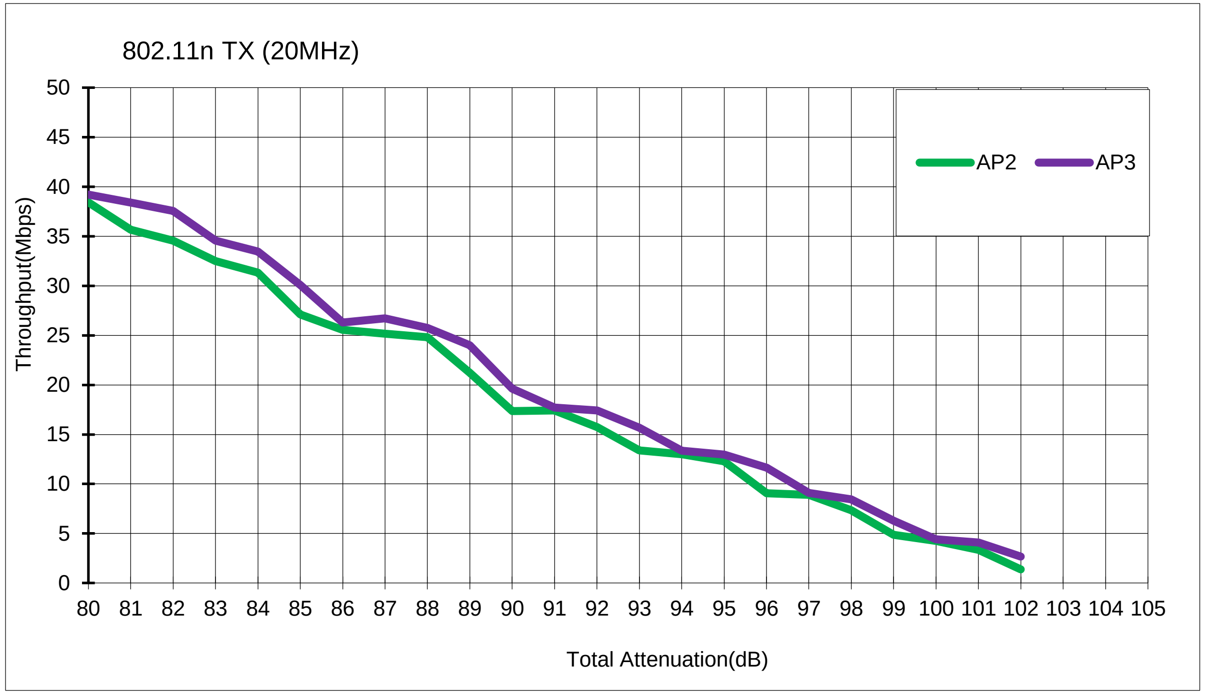
AP2 & AP3 - CH 11 (Tx mode)

CH11 TX			
Total Attenuation (dB)	AP2	AP3	AP2-AP3
65	45.833	44.05	1.783
75	45.205	44.423	0.782
80	38.437	39.222	-0.785
81	35.667	38.407	-2.74
82	34.575	37.558	-2.983
83	32.493	34.568	-2.075
84	31.348	33.467	-2.119
85	27.12	30.083	-2.963
86	25.571	26.302	-0.731
87	25.173	26.731	-1.558
88	24.814	25.759	-0.945
89	21.247	24.012	-2.765
90	17.356	19.619	-2.263
91	17.423	17.706	-0.283
92	15.753	17.425	-1.672
93	13.392	15.667	-2.275
94	13.001	13.341	-0.34
95	12.282	12.961	-0.679
96	9.074	11.646	-2.572
97	8.898	9.086	-0.188
98	7.349	8.445	-1.096
99	4.867	6.283	-1.416
100	4.265	4.412	-0.147
101	3.341	4.09	-0.749
102	1.385	2.669	-1.284



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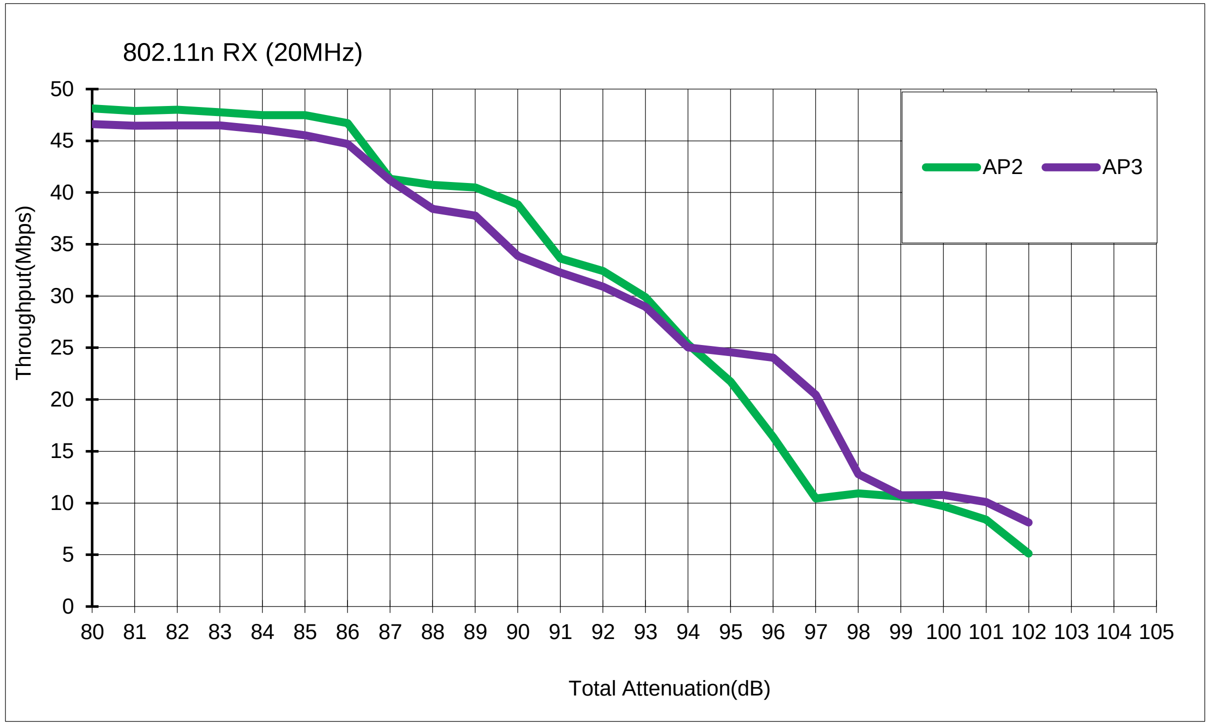
AP2 & AP3 - CH 11 (Rx mode)

CH11 RX			
Total Attenuation (dB)	AP2	AP3	AP2-AP3
65	48.661	46.667	1.994
75	48.148	46.727	1.421
80	48.139	46.609	1.53
81	47.883	46.468	1.415
82	47.996	46.475	1.521
83	47.758	46.477	1.281
84	47.475	46.088	1.387
85	47.47	45.522	1.948
86	46.716	44.692	2.024
87	41.33	41.159	0.171
88	40.736	38.41	2.326
89	40.482	37.78	2.702
90	38.852	33.882	4.97
91	33.631	32.273	1.358
92	32.43	30.91	1.52
93	29.887	28.958	0.929
94	25.348	25.014	0.334
95	21.719	24.562	-2.843
96	16.358	24.043	-7.685
97	10.423	20.449	-10.026
98	10.925	12.793	-1.868
99	10.613	10.749	-0.136
100	9.693	10.772	-1.079
101	8.401	10.11	-1.709
102	5.102	8.101	-2.999



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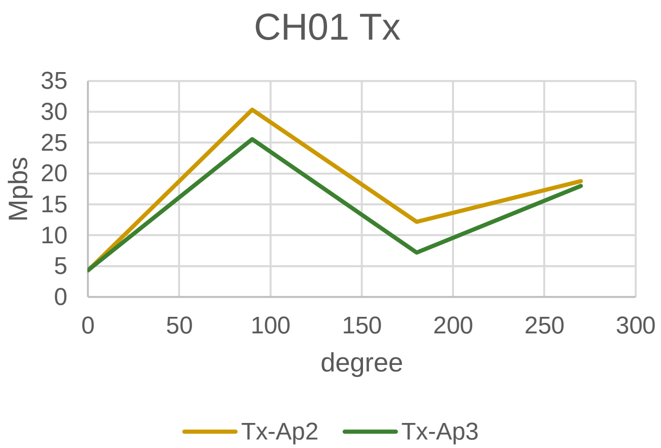
13.3” Notebook: CH01(1/3)

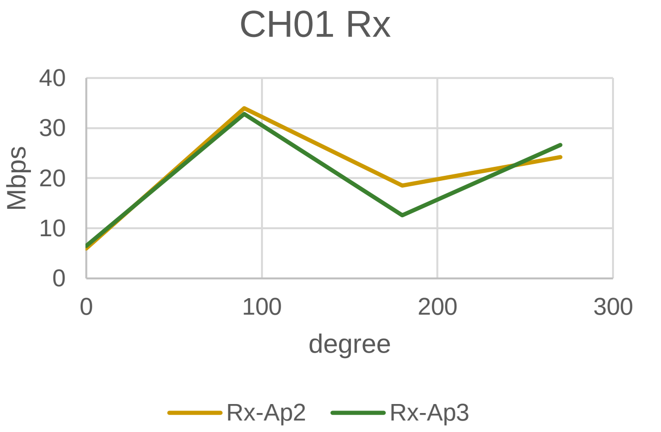
(AP-2)

實測衰減		110deg (Ant 130cm) CH01		
CH01 86db		86db	Tx	Rx
衰減器A	39	0	4.304	5.93
衰減器C	39	30		
		60		
		90	30.348	33.976
		120		
		150		
		180	12.19	18.552
		210		
		240		
		270	18.772	24.207
		300		
		330		
		Average	16.4035	20.66625

(AP-3)

實測衰減		110deg (Ant 130cm) CH01		
CH01 86db		86db	Tx	Rx
衰減器A	39	0	4.317	6.444
衰減器C	39	30		
		60		
		90	25.568	32.783
		120		
		150		
		180	7.191	12.565
		210		
		240		
		270	18.015	26.627
		300		
		330		
		Average	13.77275	19.60475





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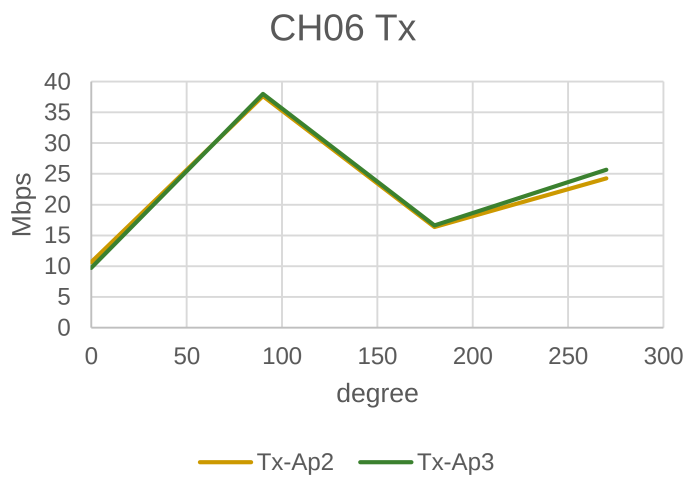
13.3” Notebook: CH06(2/3)

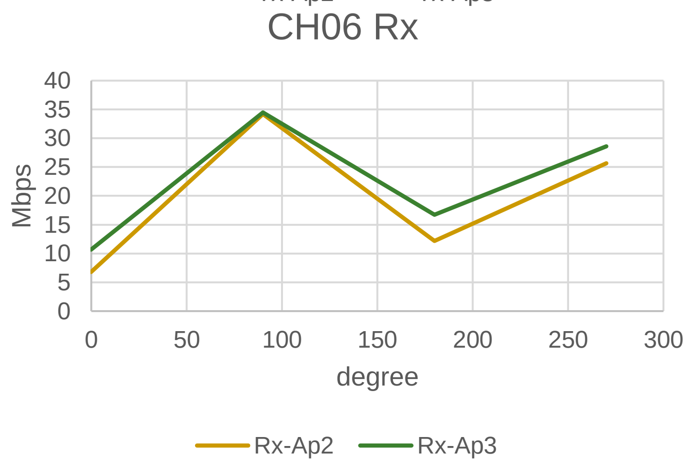
(AP-2)

實測衰減		110deg (Ant 130cm) CH06		
CH06 86db		86db	Tx	Rx
衰減器A	37	0	10.624	6.775
衰減器C	39	30		
		60		
		90	37.634	34.184
		120		
		150		
		180	16.372	12.181
		210		
		240		
		270	24.249	25.642
		300		
		330		
		Average	22.2197 5	19.6955

(AP-3)

實測衰減		110deg (Ant 130cm) CH06		
CH06 86db		86db	Tx	Rx
衰減器A	37	0	9.708	10.666
衰減器C	39	30		
		60		
		90	38.023	34.468
		120		
		150		
		180	16.618	16.702
		210		
		240		
		270	25.702	28.589
		300		
		330		
		Average	22.51275	22.60625





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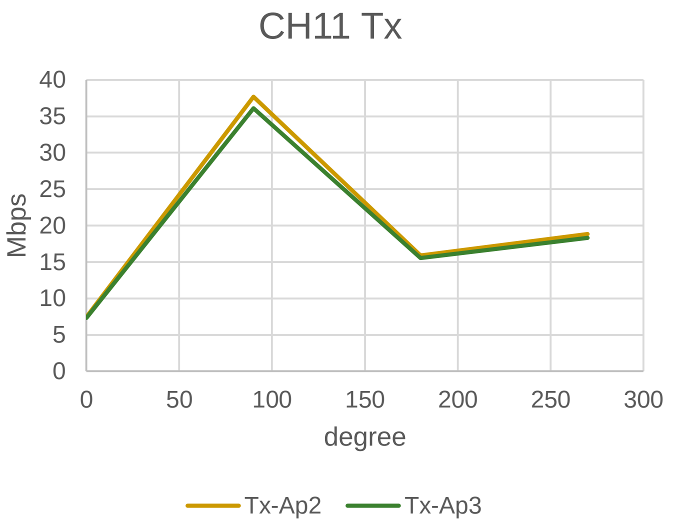
13.3” Notebook: CH11(3/3)

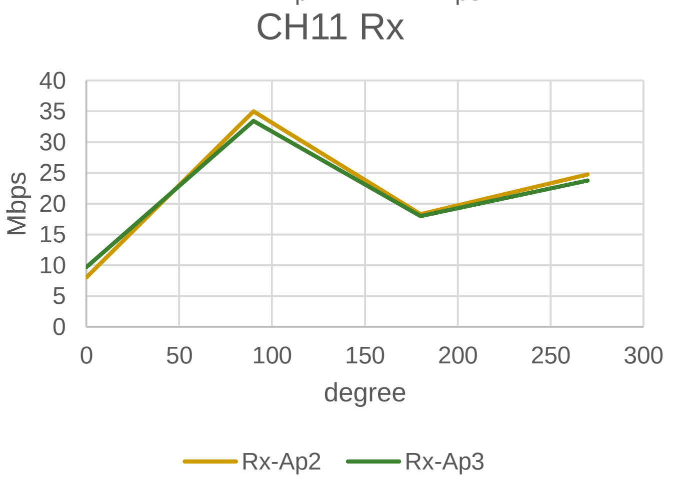
(AP-2)

實測衰減		110deg (Ant 130cm) CH11		
CH11 86db		86db	Tx	Rx
衰減器A	37	0	7.456	8.043
衰減器C	39	30		
		60		
		90	37.682	34.978
		120		
		150		
		180	15.904	18.289
		210		
		240		
		270	18.86	24.769
		300		
		330		
		Average	19.9755	21.5197 5

(AP-3)

實測衰減		110deg (Ant 130cm) CH11		
CH11 86db		86db	Tx	Rx
衰減器A	37	0	7.339	9.695
衰減器C	39	30		
		60		
		90	36.104	33.412
		120		
		150		
		180	15.546	17.979
		210		
		240		
		270	18.292	23.777
		300		
		330		
		Average	19.3202 5	21.2157 5





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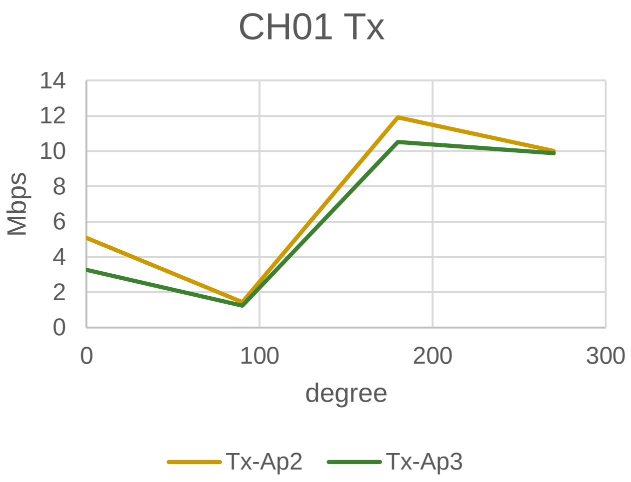
15” Notebook: CH01(1/3)

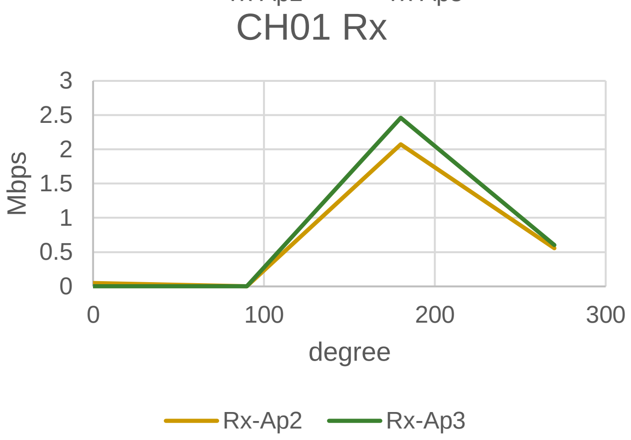
(AP-2)

實測衰減		110deg (Ant 105cm) CH01		
CH01 86db		86db	Tx	Rx
衰減器A	39	0	5.072	0.047
衰減器C	39	30		
		60		
		90	1.444	0
		120		
		150		
		180	11.915	2.071
		210		
		240		
		270	10.014	0.559
		300		
		330		
		Average	7.11125	0.66925

(AP-3)

實測衰減		110deg (Ant 105cm) CH01		
CH01 86db		86db	Tx	Rx
衰減器A	39	0	3.27	0
衰減器C	39	30		
		60		
		90	1.247	0
		120		
		150		
		180	10.521	2.461
		210		
		240		
		270	9.892	0.603
		300		
		330		
		Average	6.2325	0.766





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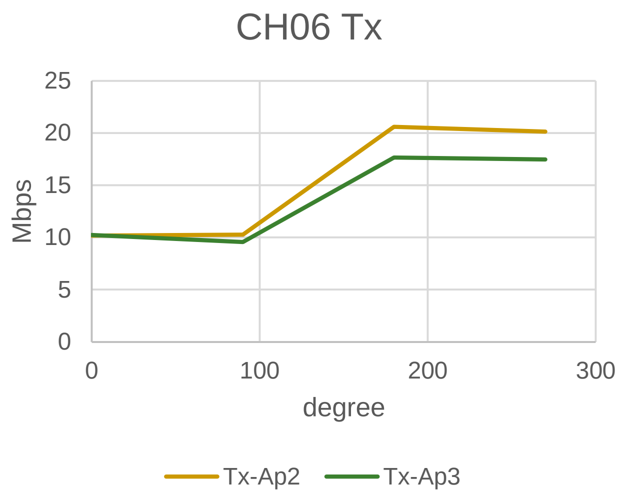
15” Notebook: CH06(2/3)

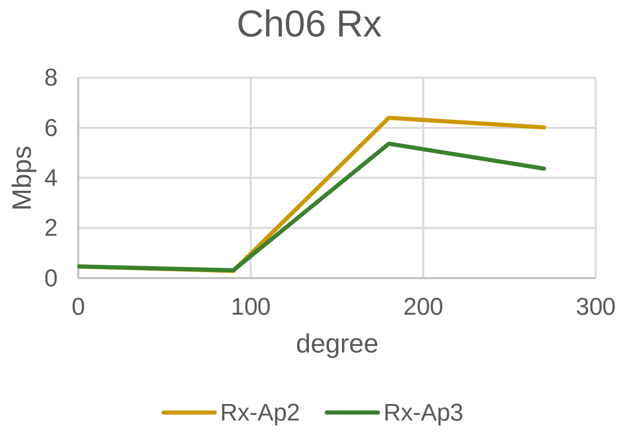
(AP-2)

實測衰減		110deg (Ant 105cm) CH06		
CH06 86db		86db	Tx	Rx
衰減器A	37	0	10.18	0.464
衰減器C	39	30		
		60		
		90	10.251	0.281
		120		
		150		
		180	20.592	6.394
		210		
		240		
		270	20.126	6.015
		300		
		330		
		Average	15.28725	3.2885

(AP-3)

實測衰減		110deg (Ant 105cm) CH06		
CH06 86db		86db	Tx	Rx
衰減器A	37	0	10.225	0.463
衰減器C	39	30		
		60		
		90	9.556	0.307
		120		
		150		
		180	17.645	5.358
		210		
		240		
		270	17.471	4.365
		300		
		330		
		Average	13.7242 5	2.62325





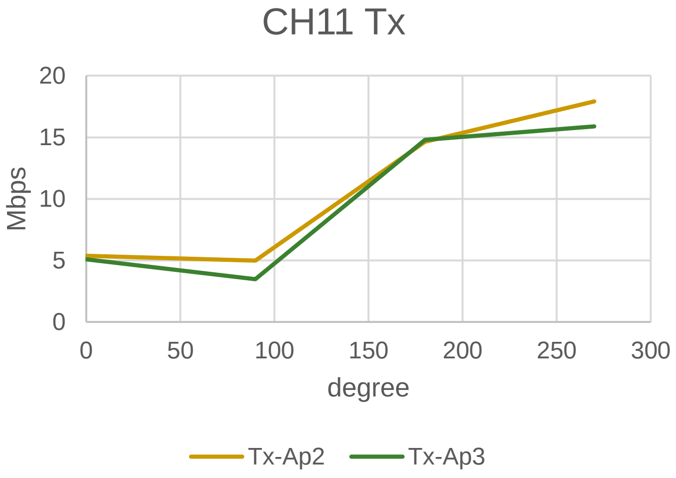
15” Notebook: CH11(3/3)

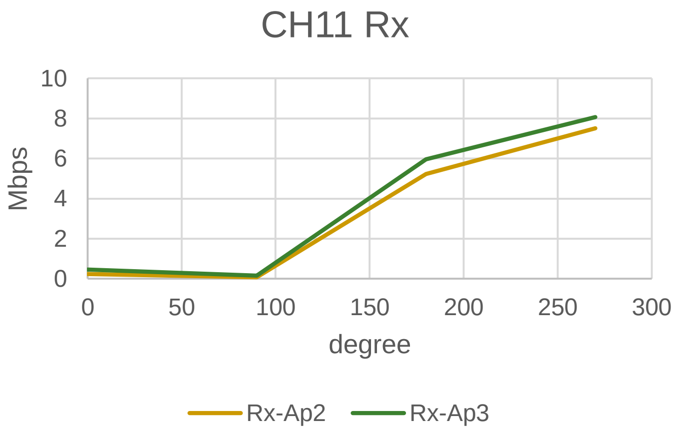
(AP-2)

實測衰減		110deg (Ant 105cm) CH11		
CH11 86db		86db	Tx	Rx
衰減器A	37	0	5.365	0.229
衰減器C	39	30		
		60		
		90	4.984	0.081
		120		
		150		
		180	14.629	5.223
		210		
		240		
		270	17.908	7.509
		300		
		330		
		Average	10.7215	3.2605

(AP-3)

實測衰減		110deg (Ant 105cm) CH11		
CH11 86db		86db	Tx	Rx
衰減器A	37	0	5.097	0.458
衰減器C	39	30		
		60		
		90	3.481	0.161
		120		
		150		
		180	14.792	5.968
		210		
		240		
		270	15.895	8.066
		300		
		330		
		Average	9.81625	3.66325





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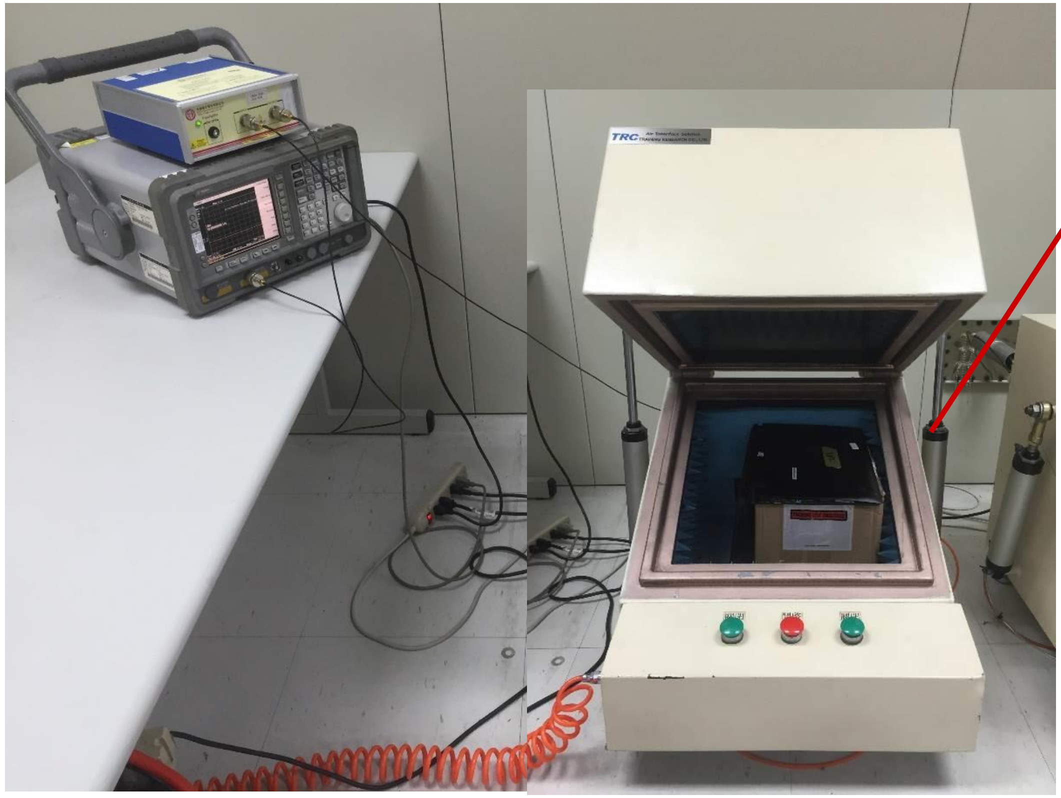
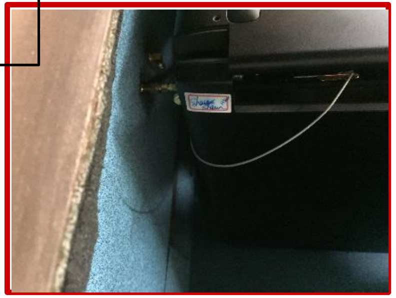
Setup for Antenna Port Noise



Complete set up view

inside view



Back view

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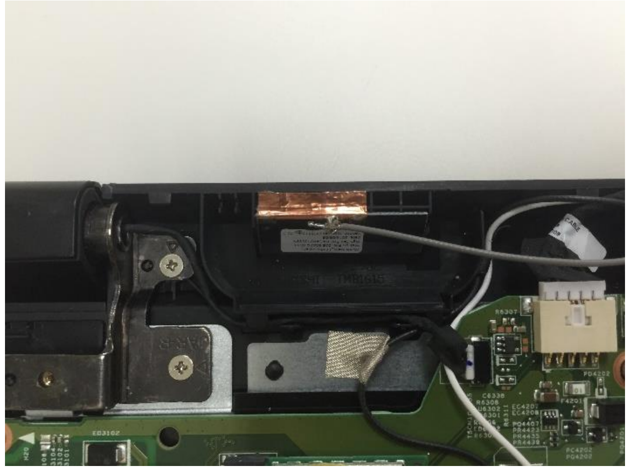
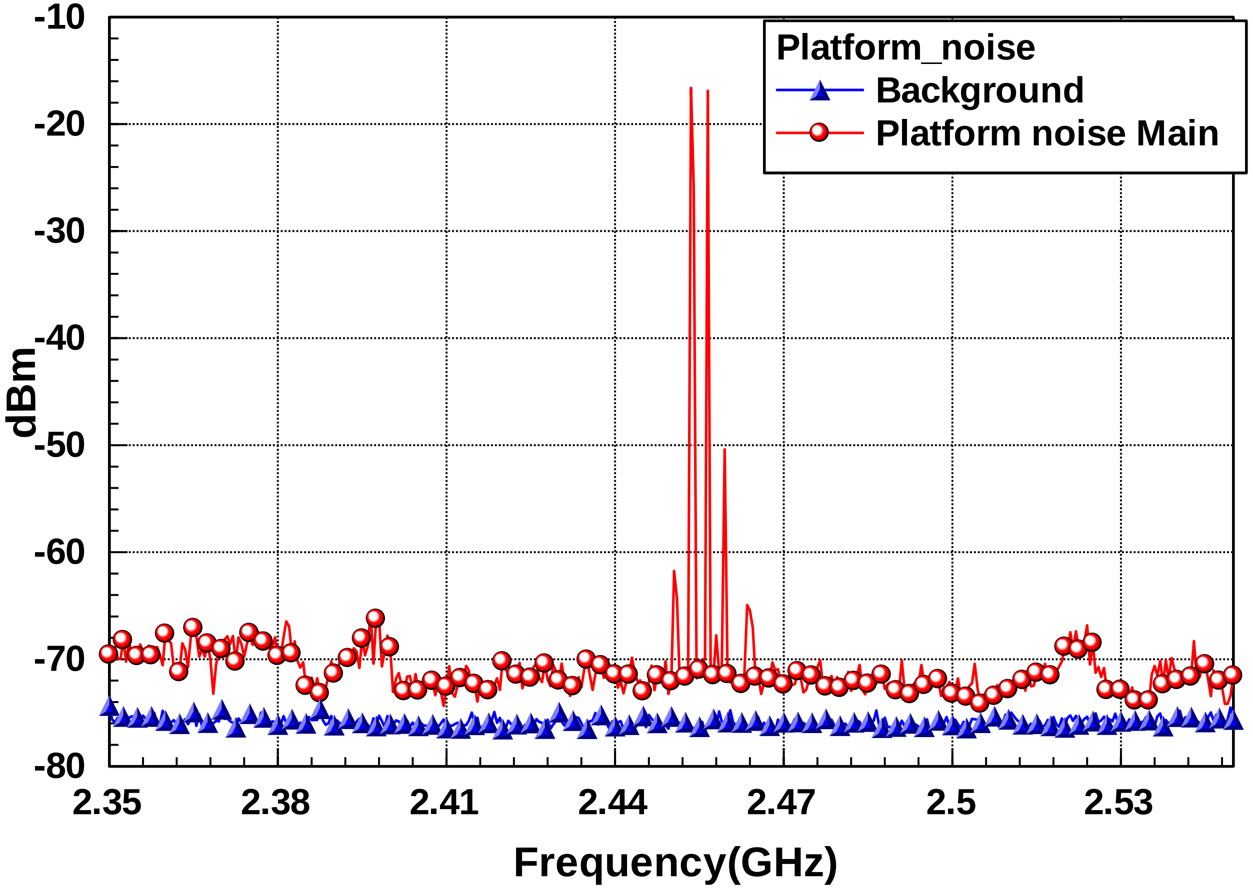
Platform Noise (WLAN_Main)



WLAN_Main_LF15V



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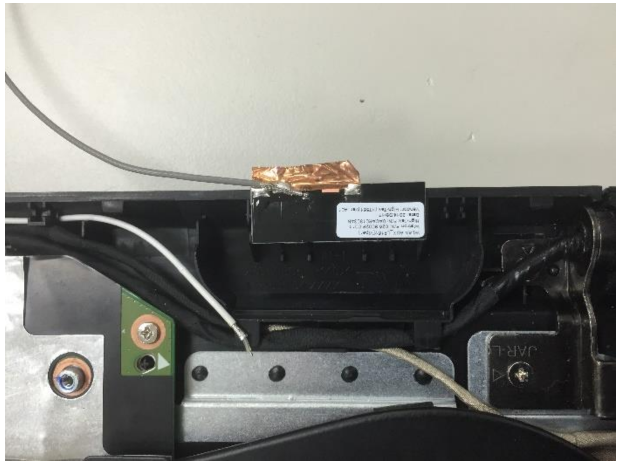
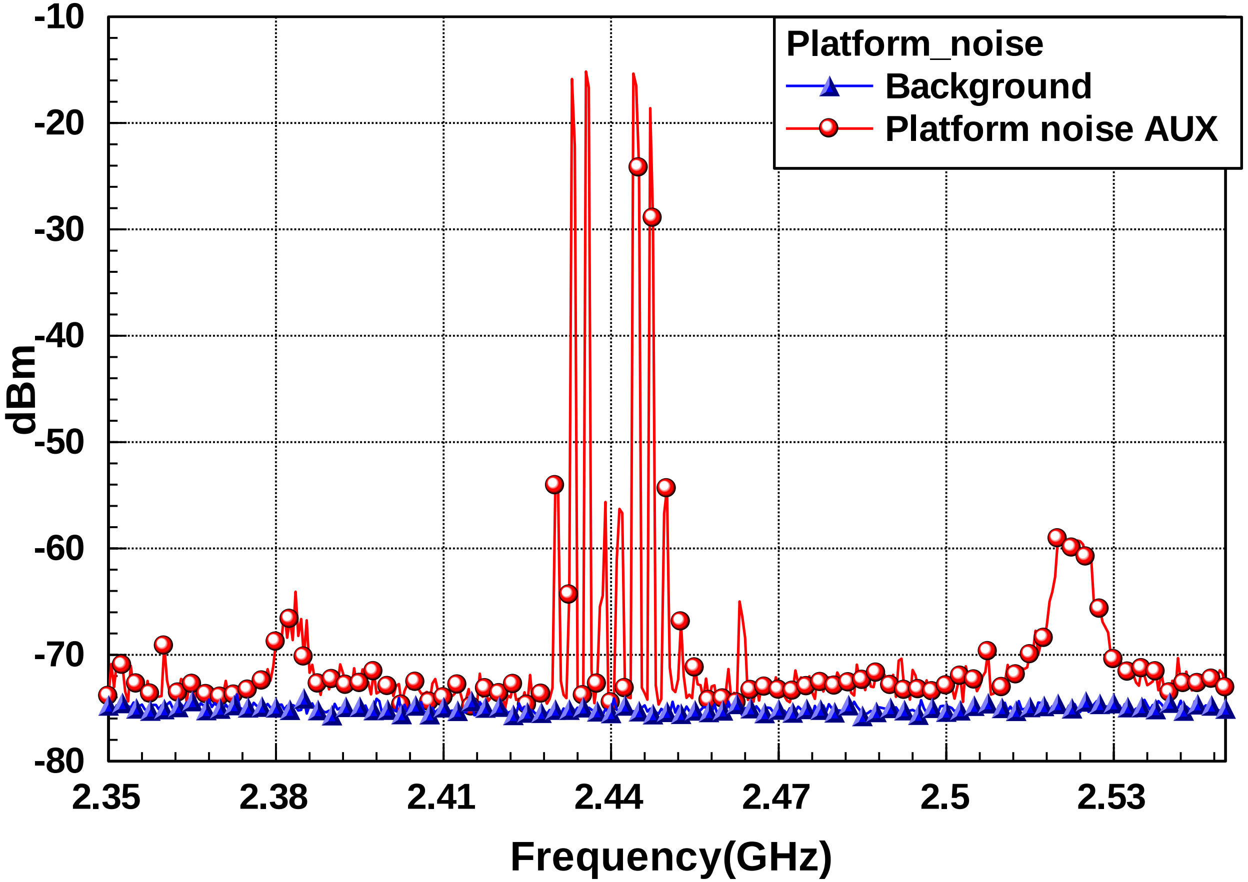
Platform Noise(WLAN_AUX)



WLAN_AUX_LF15V



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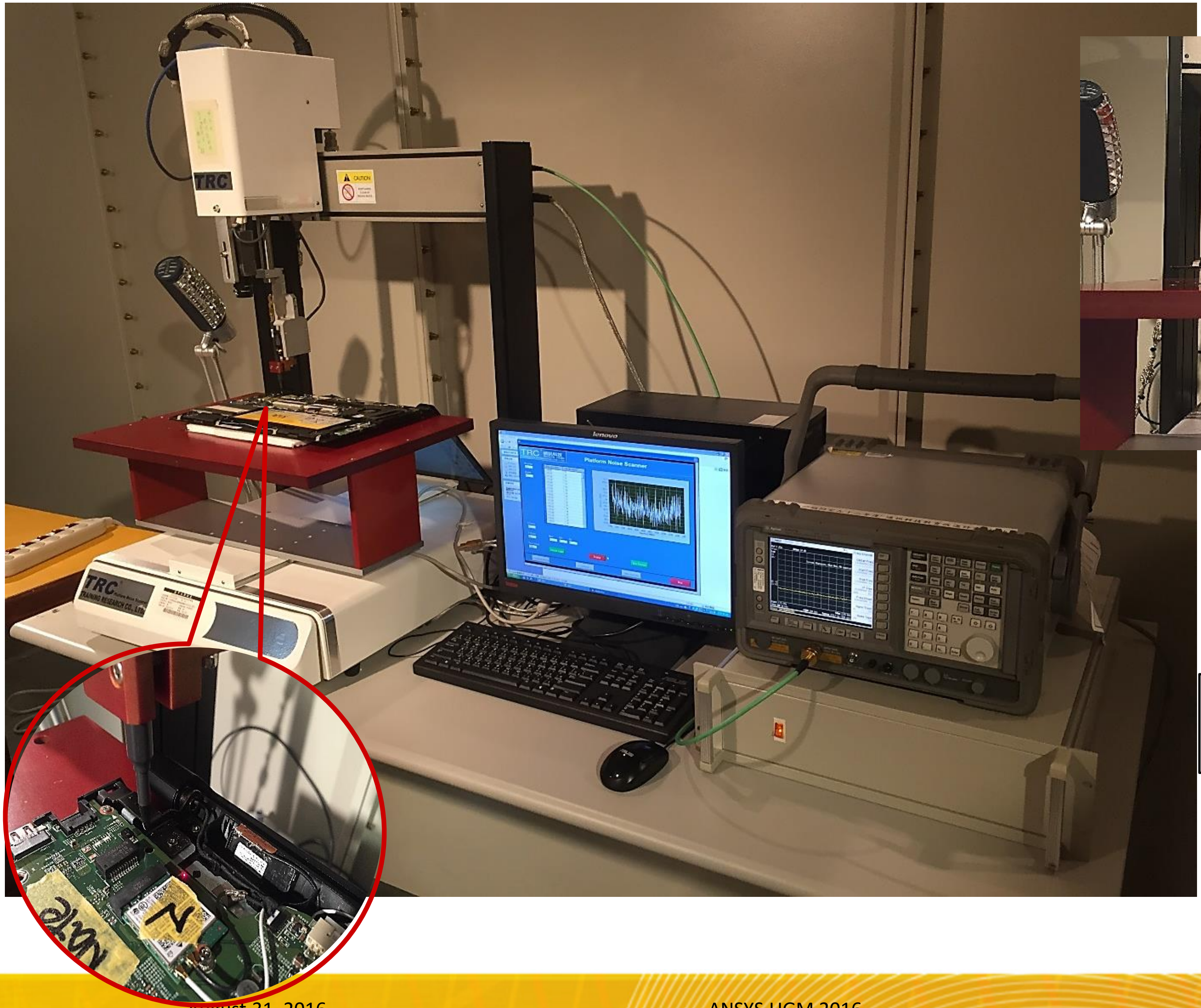
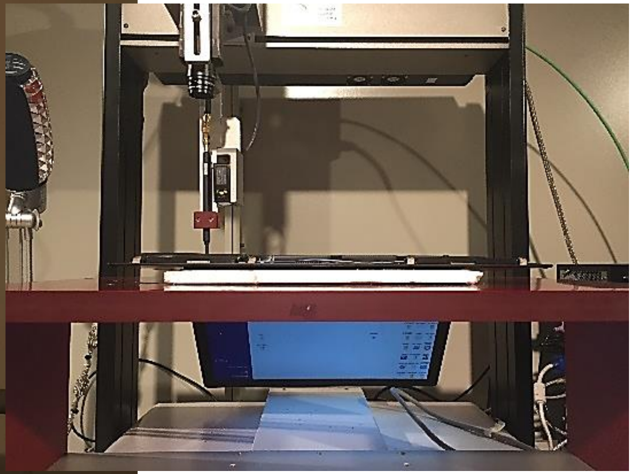
Surface Scan to Locate Noise Source





Front view

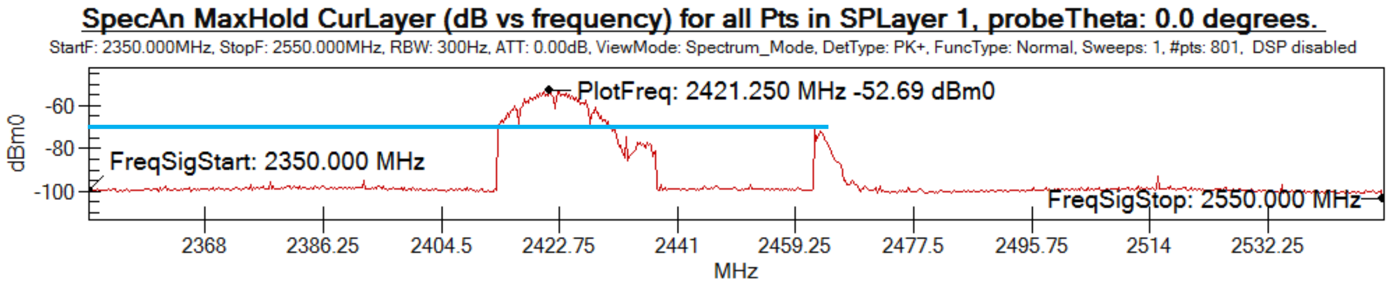
Complete setup view

ANSYS

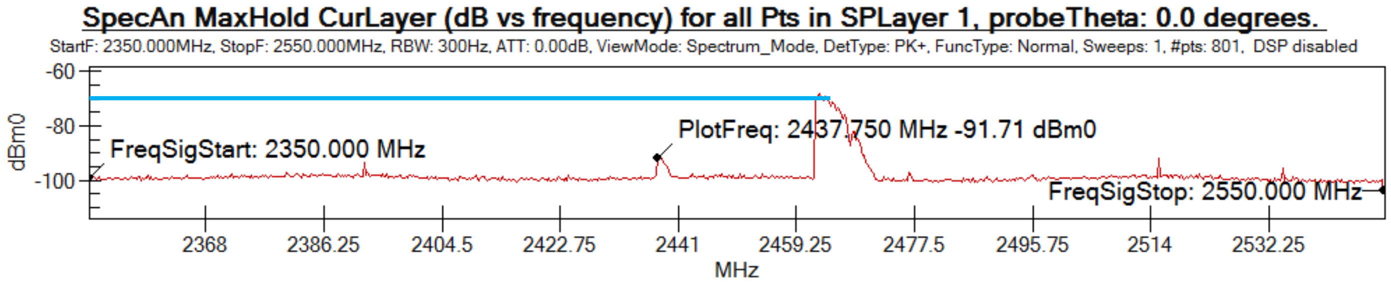
Current RFI Mitigation Practices

屏蔽材料對於雜訊抑制效果比較

未加材料_Probe 0°

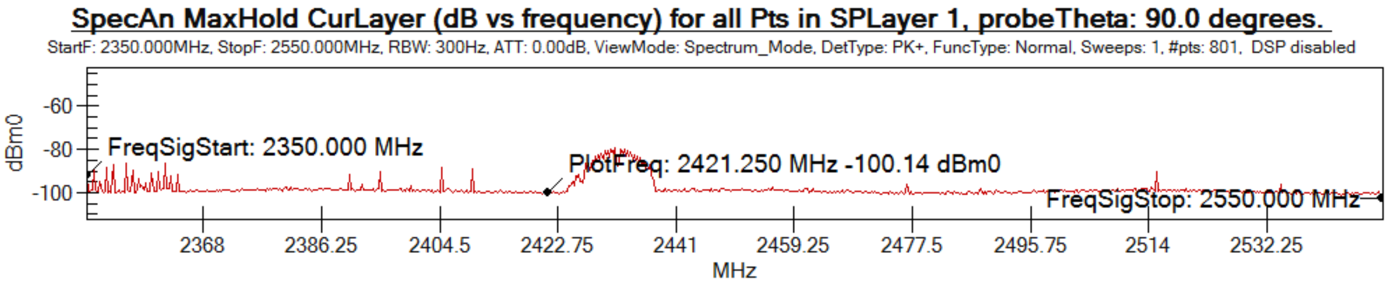


加入材料(石墨烯)_Probe 0°

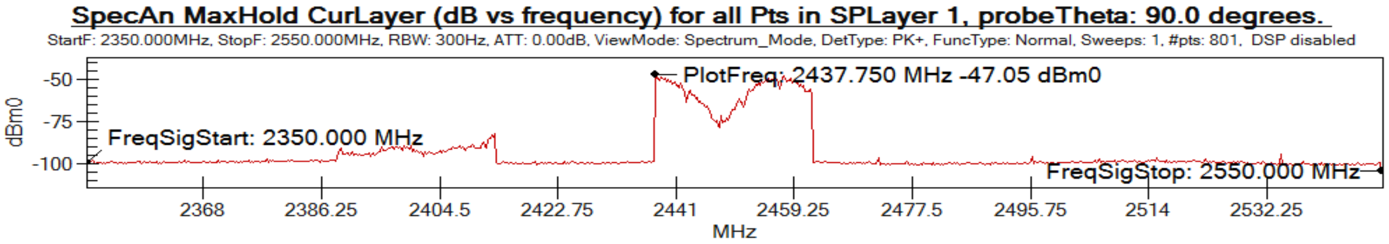


屏蔽材料對於雜訊抑制效果比較

未加材料_Probe 90°

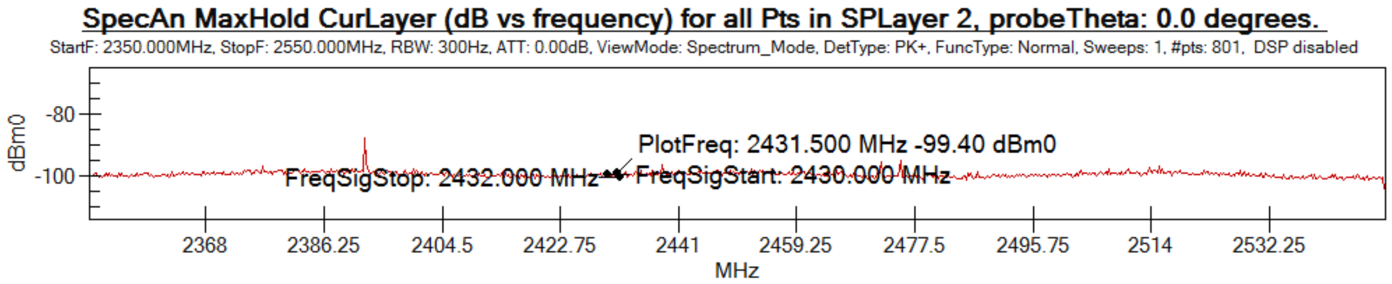


加入材料(石墨烯)_Probe 90°

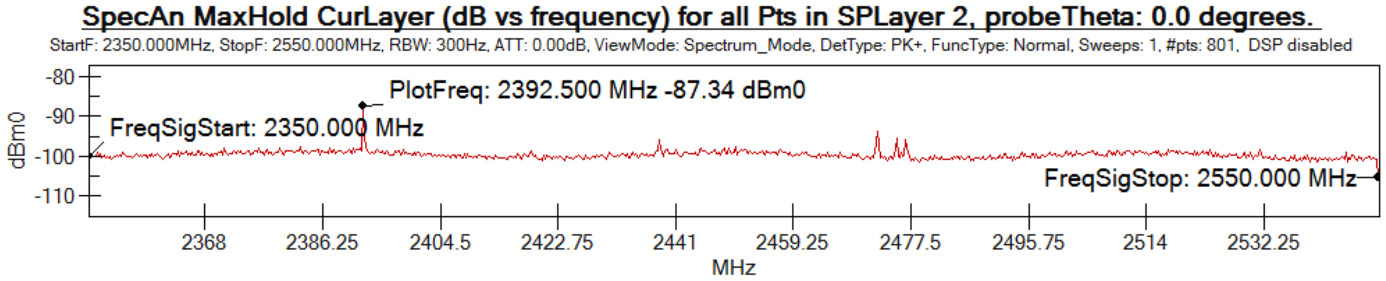


屏蔽材料對於雜訊抑制效果比較

未加材料_Probe 0˚

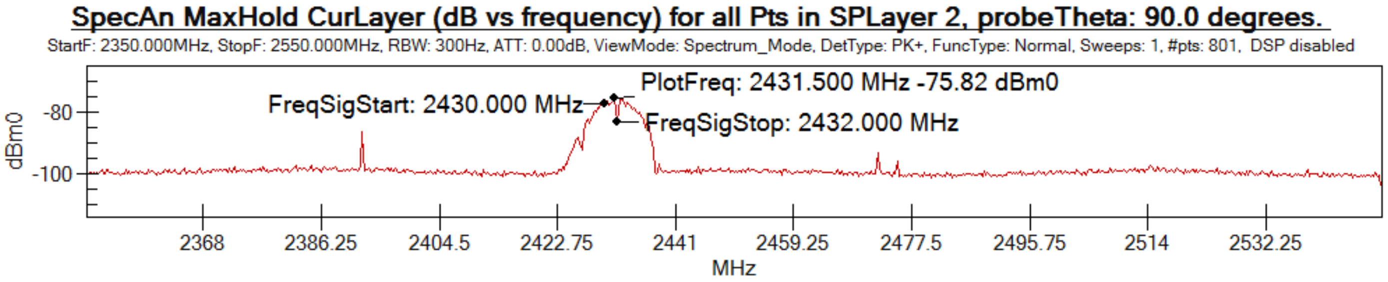


加入材料(石墨烯)_Probe 0˚

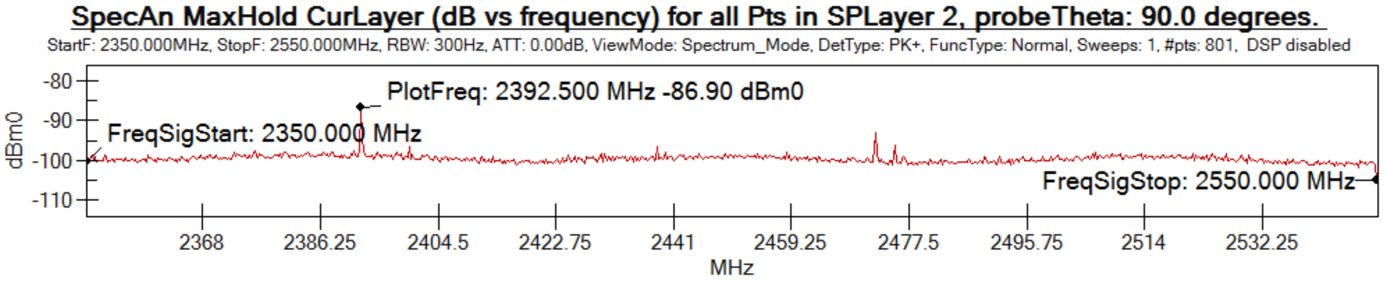


屏蔽材料對於雜訊抑制效果比較

未加材料_Probe 90˚



加入材料(石墨烯)_Probe 90˚



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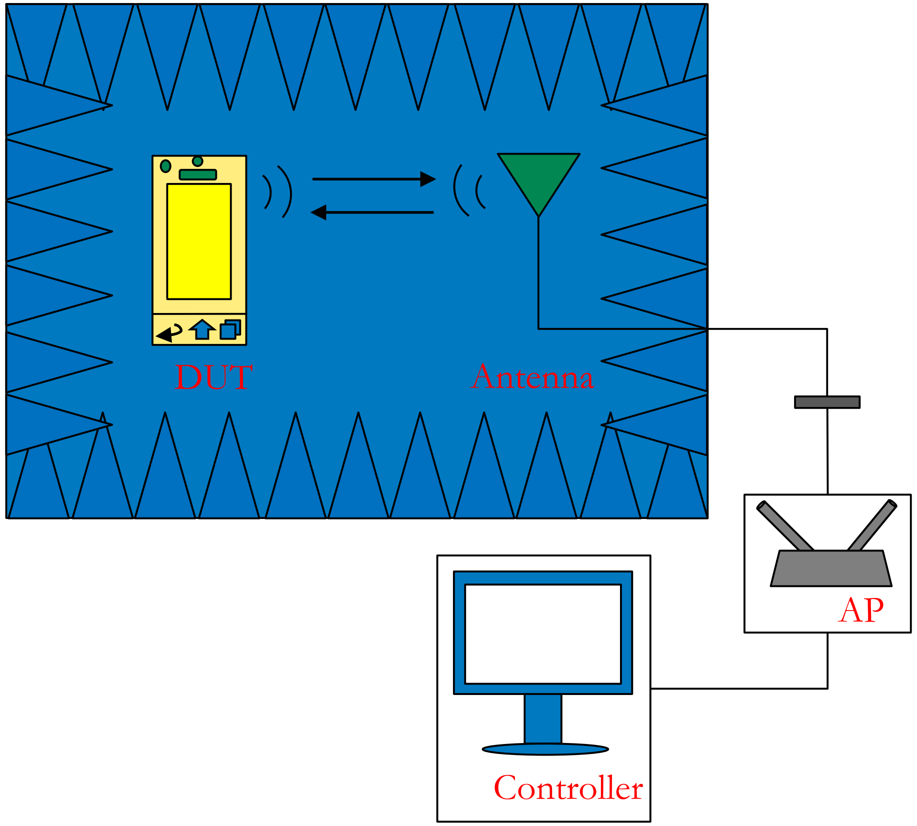
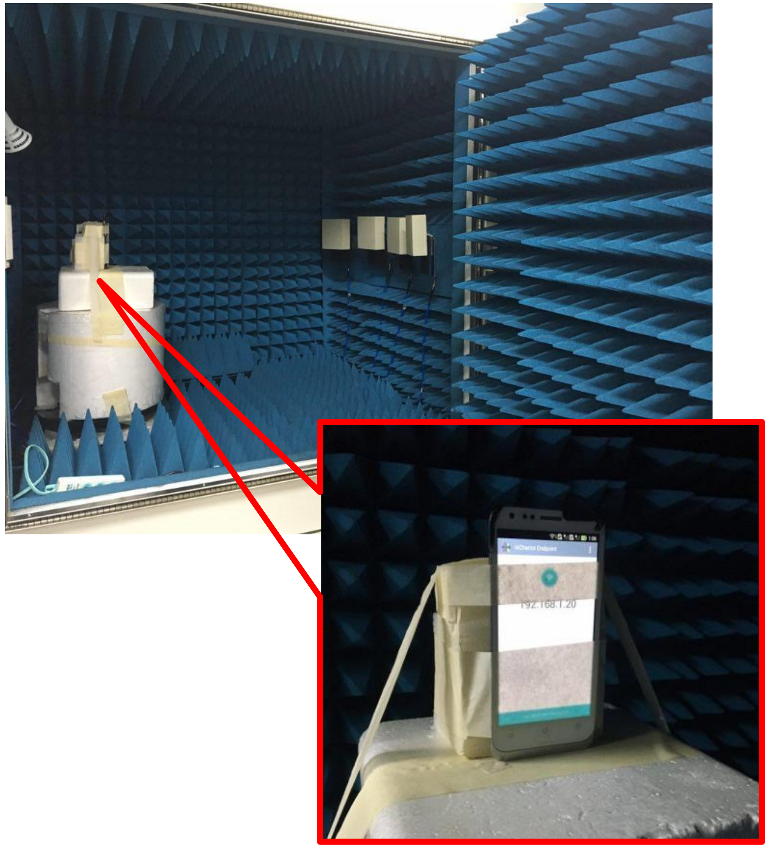
Throughput 量測

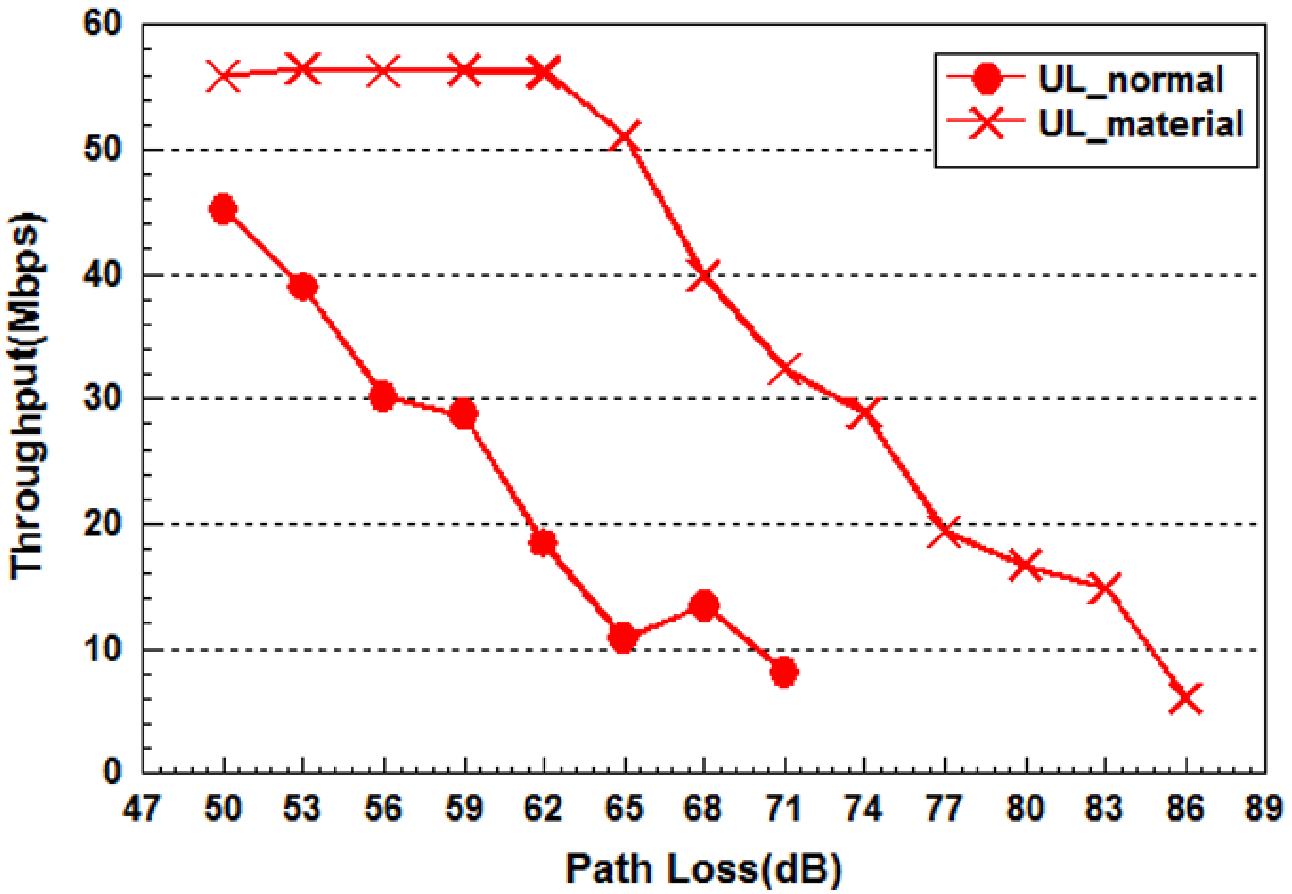
量測場地示意圖



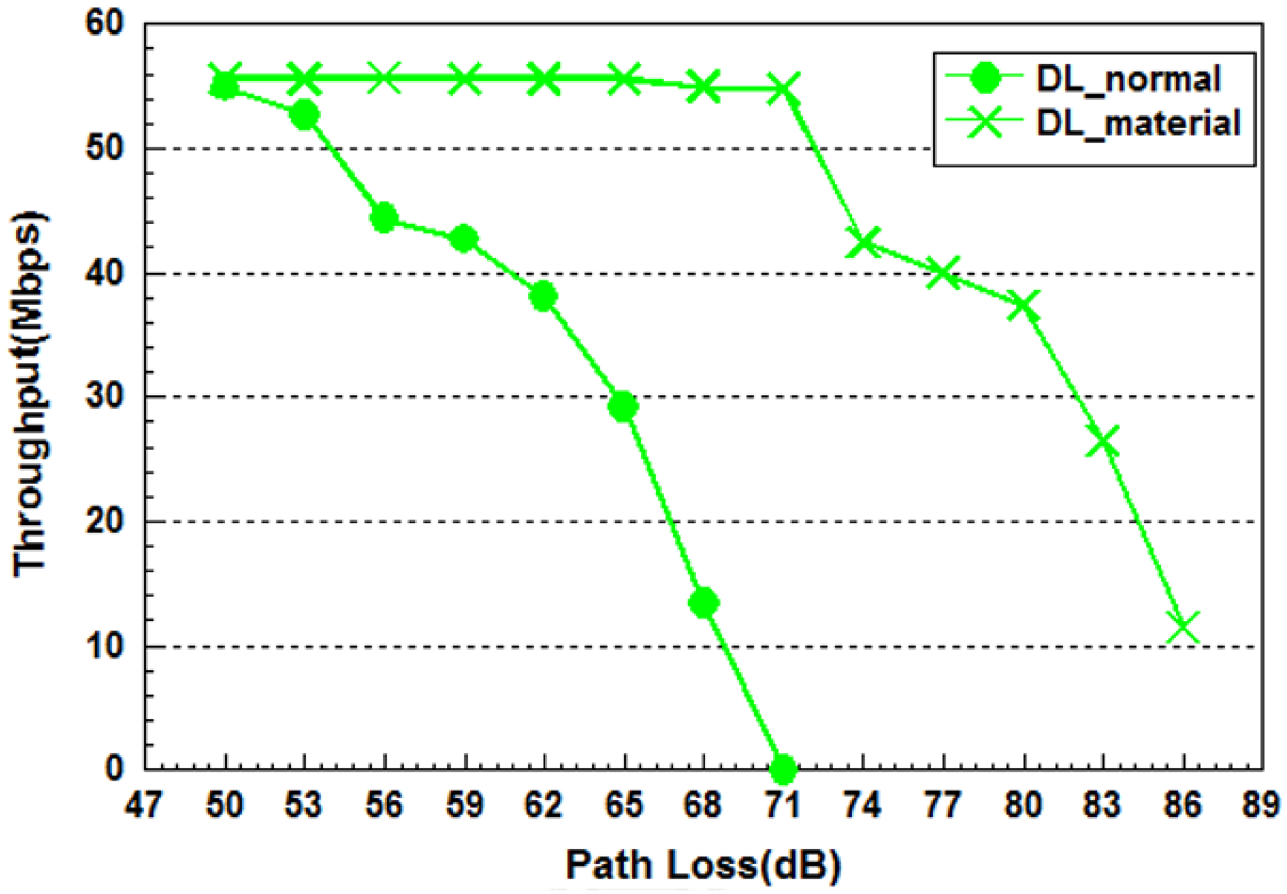
實際量測場地



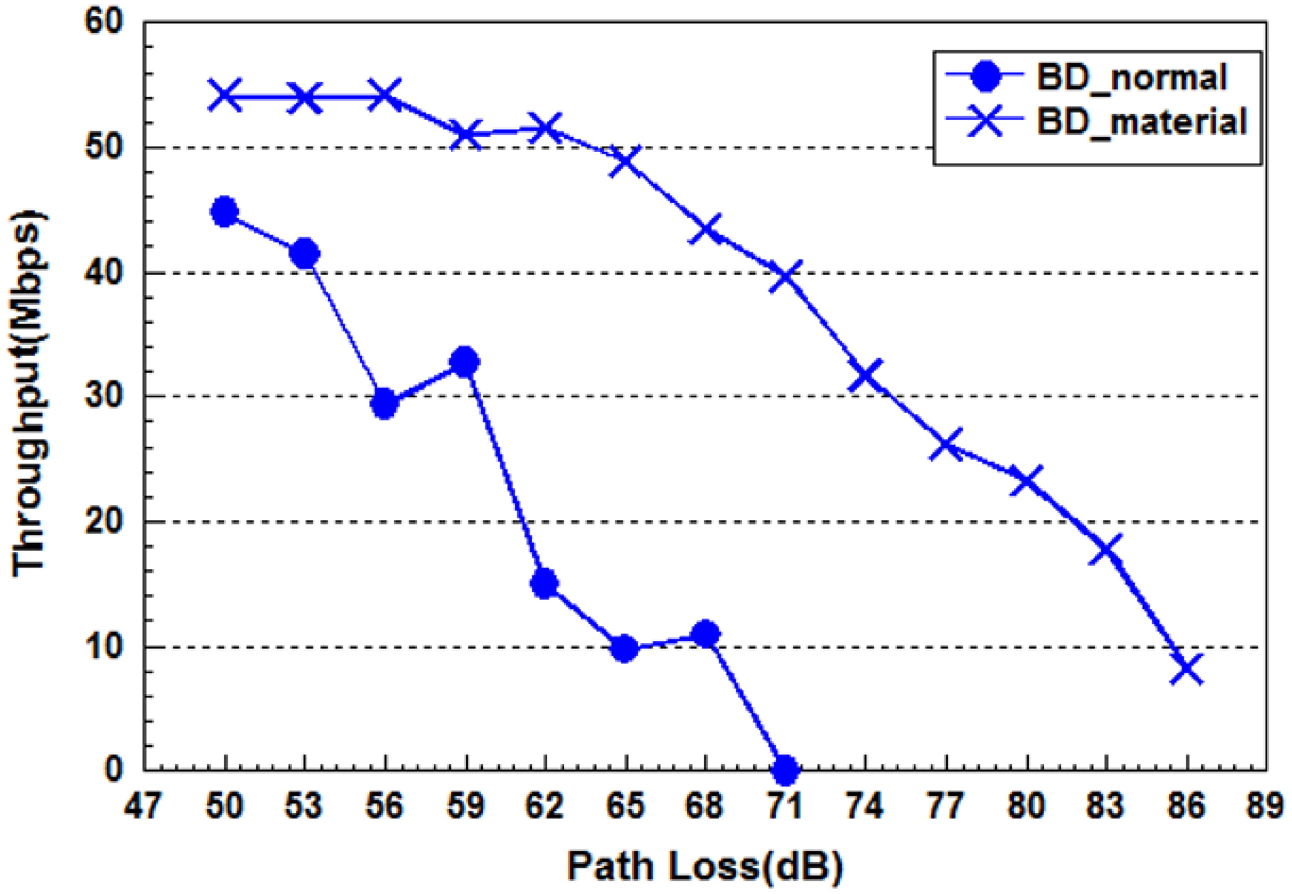
Throughput (Uplink)



Throughput (Downlink)

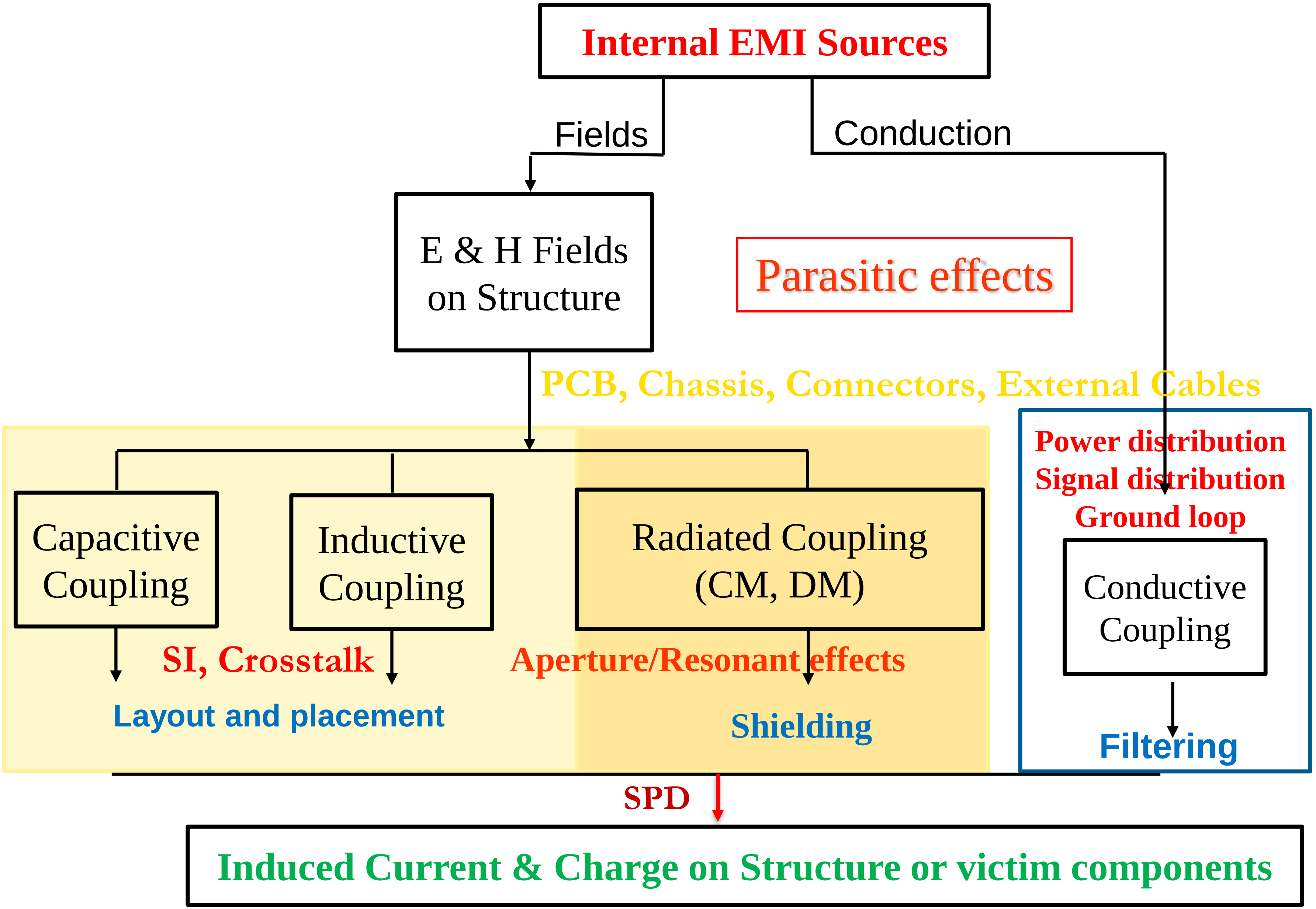


Throughput (Bidirectional)

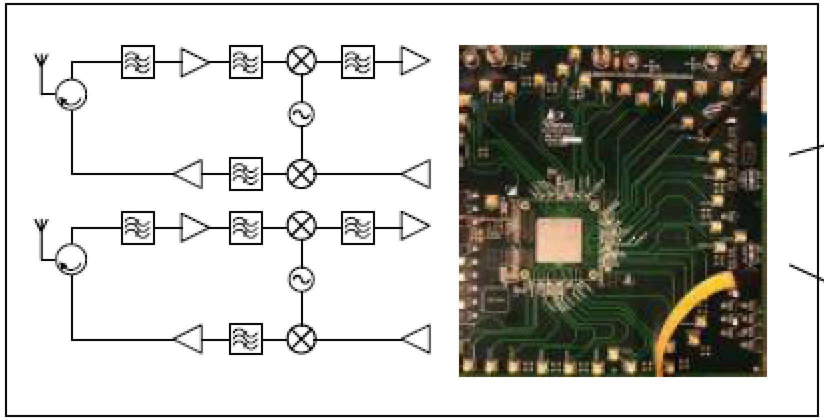


Outline

- Introduction to EMI and RFI for High-Speed Systems
- Trend of Wireless Communications and Automotive Development
- Platform Noise Impact on Throughput
- EMI Analysis of Key Components in Mobile Device
- Application of Noise Budget and Analysis Model for System Integration
- Conclusion


Internal EMI Sources
Fields
Conduction
E & H Fields on Structure
Parasitic effects
PCB, Chassis, Connectors, External Cables
Power distribution
Signal distribution
Ground loop
Capacitive Coupling
Inductive Coupling
Radiated Coupling (CM, DM)
Conductive Coupling
SI, Crosstalk
Aperture/Resonant effects
Layout and placement
Shielding
Filtering
SPD
Induced Current & Charge on Structure or victim components

Estimating RF Interference Levels in Mixed Digital/RF Designs



Interference between RF radios

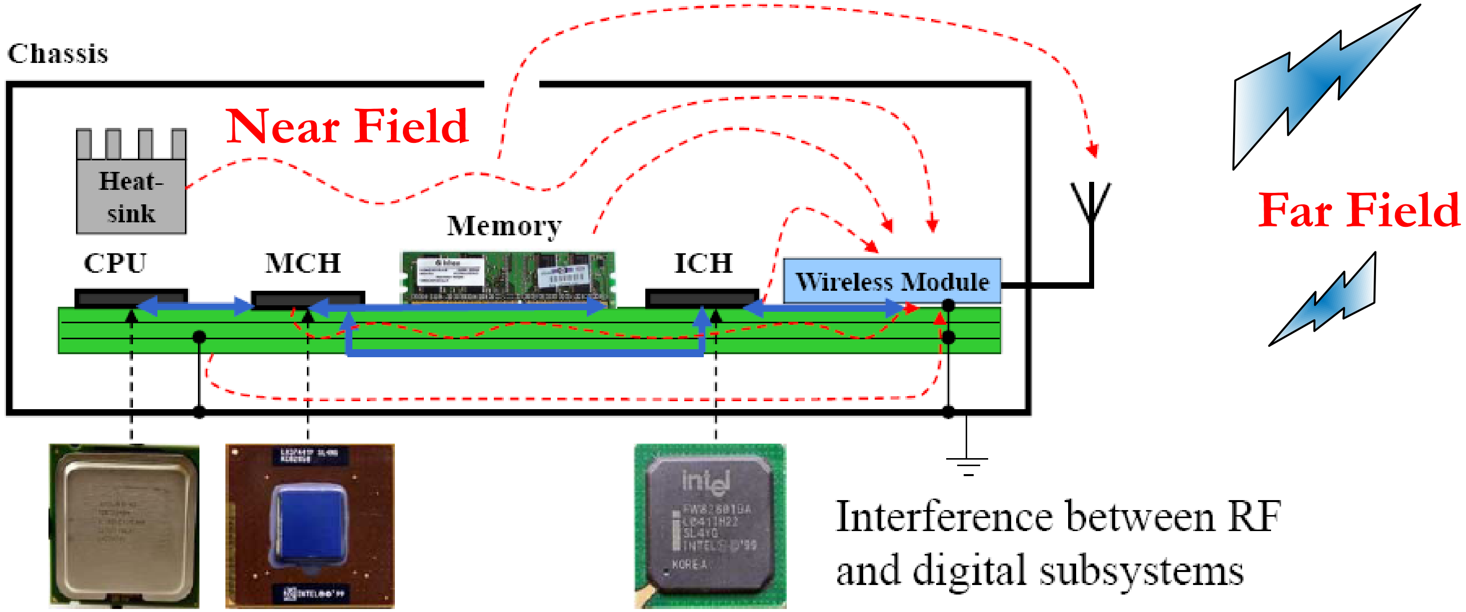
Interference between RF and digital subsystems

Sources of RFI:

- Co-channel interference
- Adjacent channel interference
- Out of band interference
- Spurious interference
- Intermodulation
- Receiver desensitization

RF receiver is very sensitive to digital noise

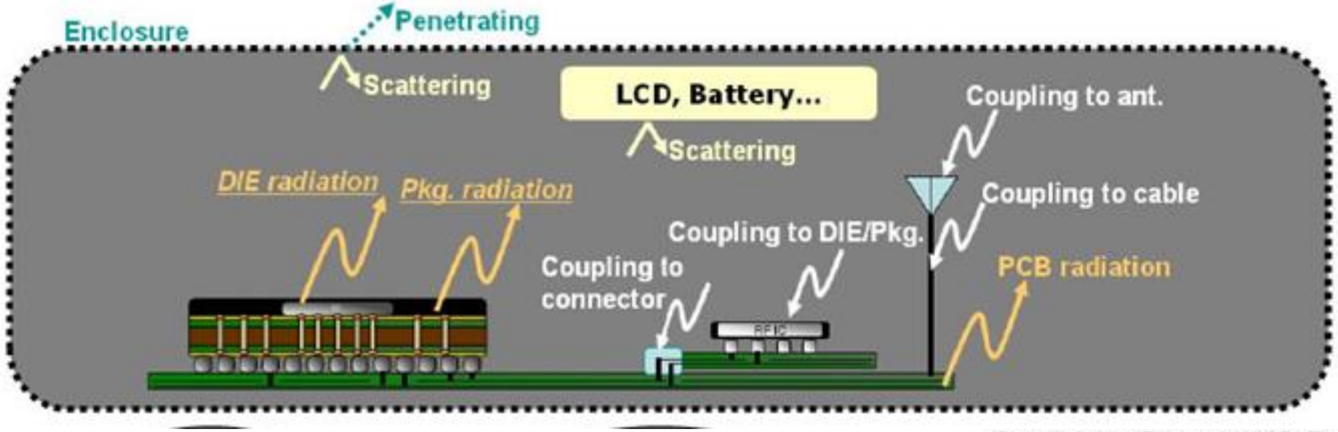
RFI/EMI Analysis for RF Devices

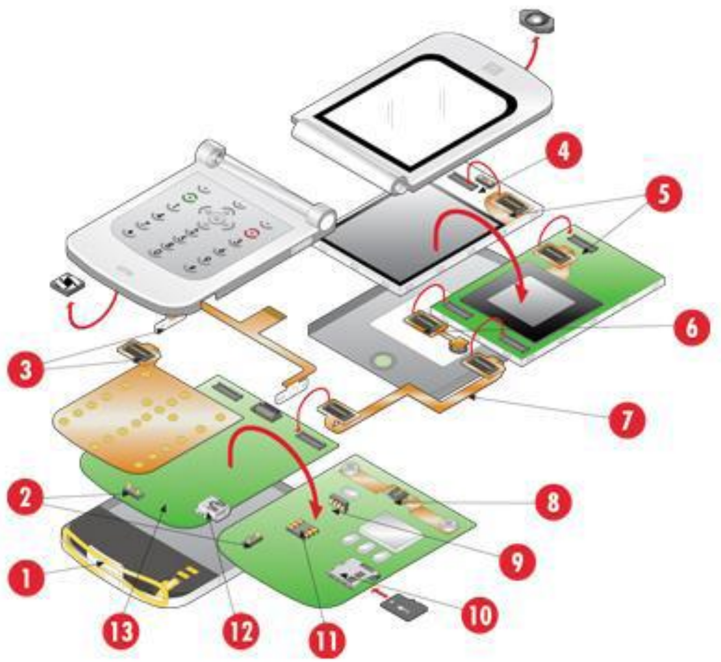


Possible coupling paths

- Radiation through aperture in chassis and picked up by antenna.
- Direct field coupling inside chassis, heat-sink radiation, high speed signal trace radiation, etc.
- Coupling through power distribution system.
- Coupling through loop formed by chassis and ground planes

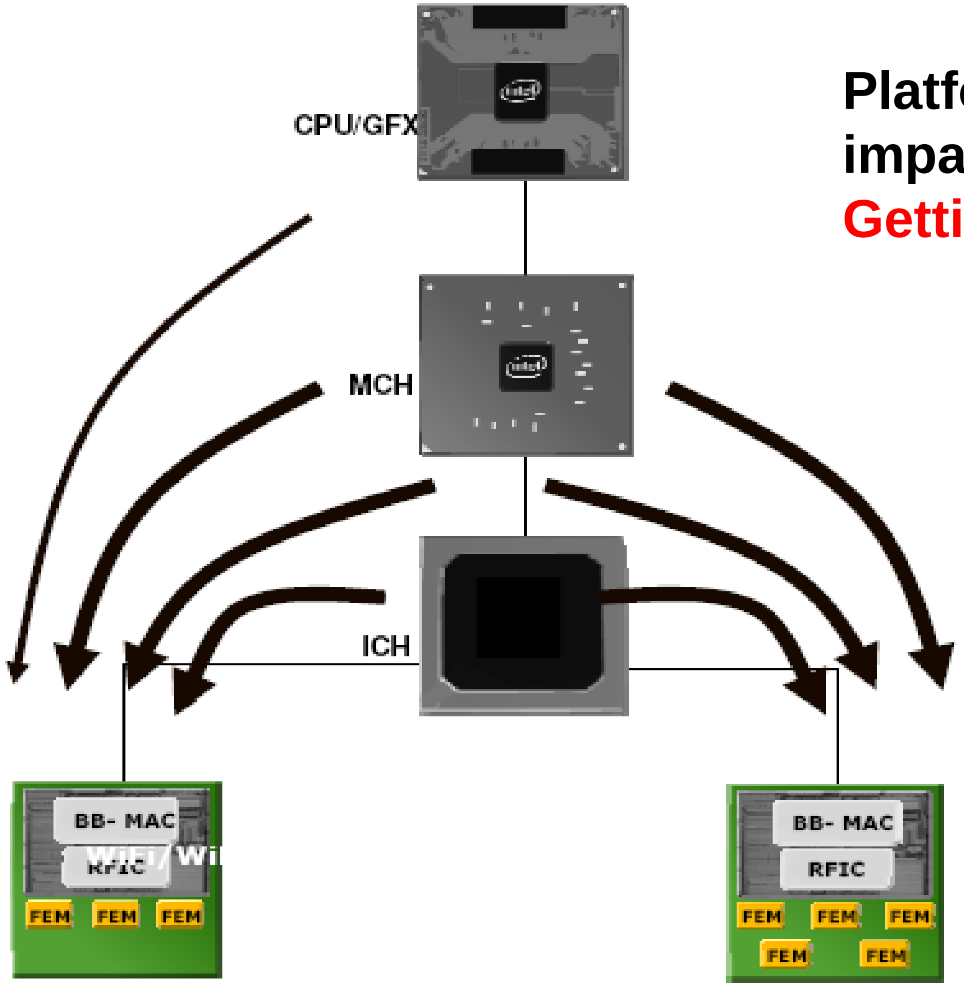
Near field Coupling Path Loss





iSuppli Apple iPhone 4 (16GB) Teardown Analysis

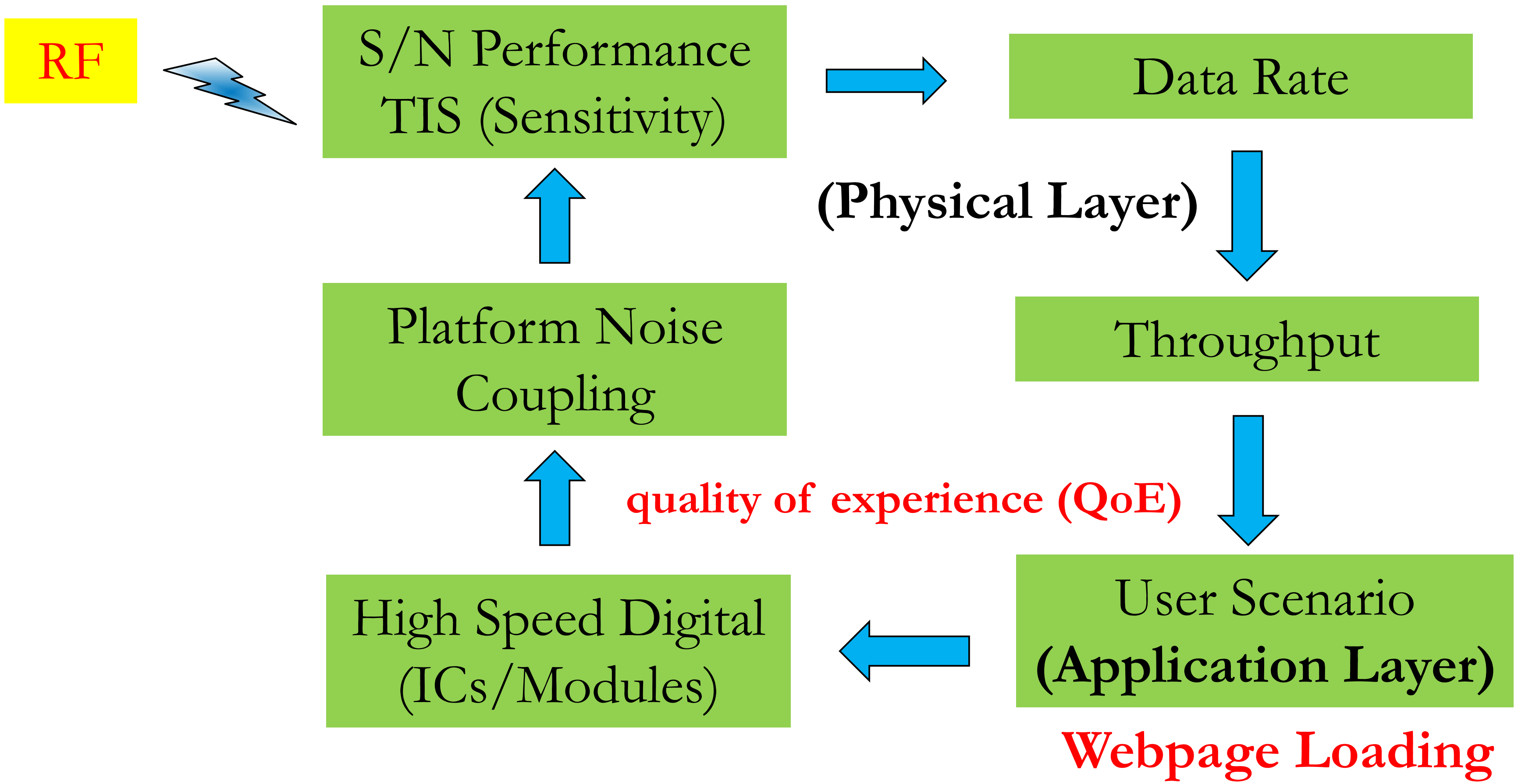
Platform Noise is a problem today and will get worse if we do nothing



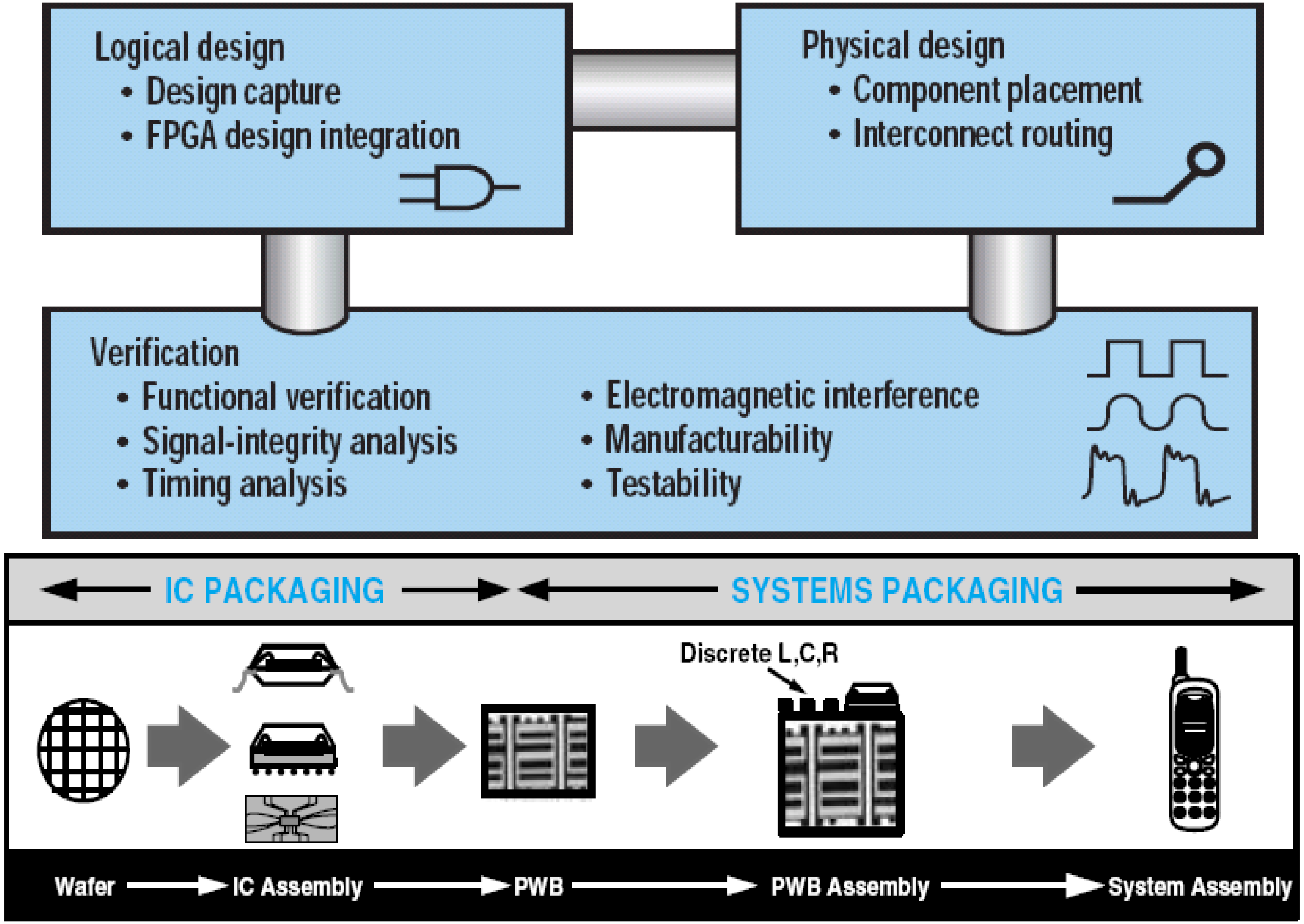
Platform RF Interference severely impacts wireless performance.
Getting worse for future platforms

- More Victim Radios
- Licensed Radios (more stringent reqs.)
- Higher GHz Sources (I/O & Components)
- UMD devices force noise closer to radios

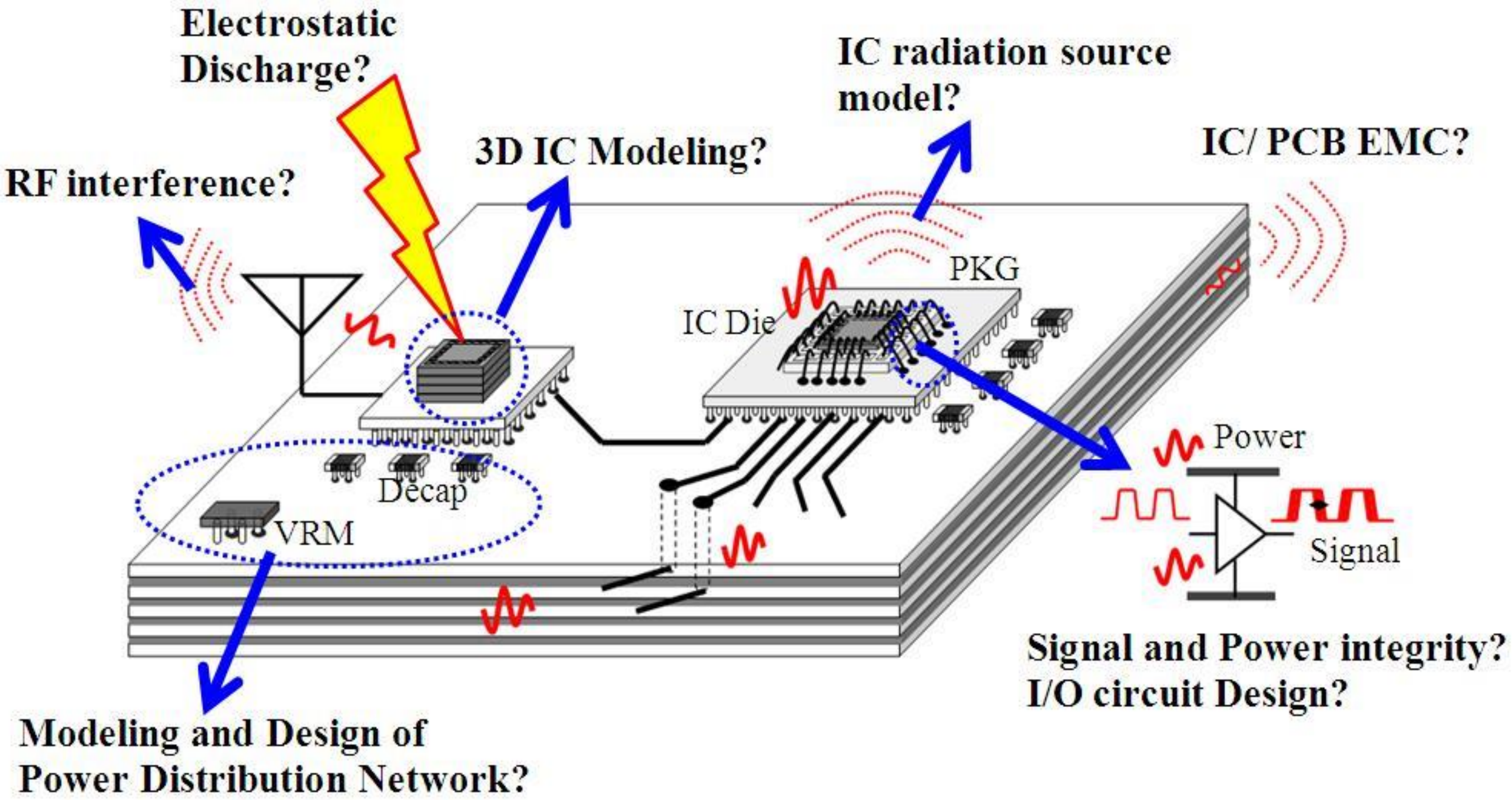
The difference between wireless link rate, actual file transfer and web browsing speed



Aspect of EMC stages



Critical industrial needs for EMC



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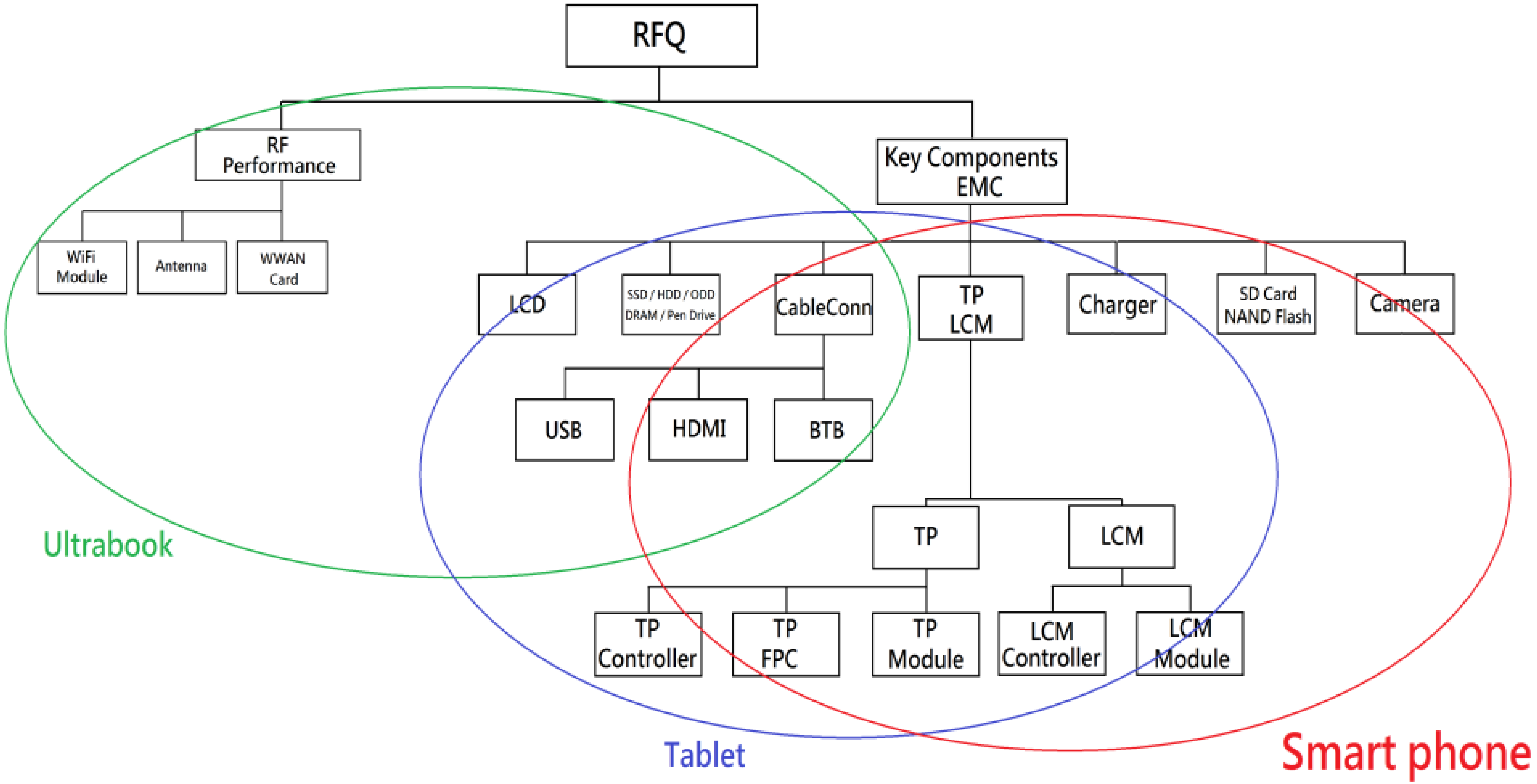
Development trends for new EMC-strategies

Individualization of products	➔ More equivalent parts ➔ Module strategy
Fast market- and technology changes	➔ Reduction of development time
Electronics is ubiquitous	➔ Growing complexity

Consequence

- Impact of component testing rises ↑
- Impact of product testing diminishes ↓

Key Components for Wireless Devices



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Link budget vs. Noise budget

Link Budget

- Specify all the component
- Specification like insertion loss, VSWR, NF, from antenna to I/Q demodulator.

ANTENNA GAIN	
DIPLEXER INSERTION LOSS	
MISMATCHING LOSS	
LNA GAIN	
LNA NOISE FIGURE	
SAW FILTER LOSS	
MIXER CONVERSTION LOSS	
SAW FILTER LOSS	
I/Q CONVERSTION LOSS	

Noise Budget

- Specify the Noise power Specification for different component at different location

Noise Power	
CPU	
NORTH BRIDGE(LVDS DIRVER….)	
MEMORY	
LVDS SOKET	
LVDS FLAT FLEX CABLE	
LCD PANEL (T-CON, BACKLIGHT)	
WEB CAM	
MINI COAXIAL CABLE FOR RF	
SOUTH BRIDGE	

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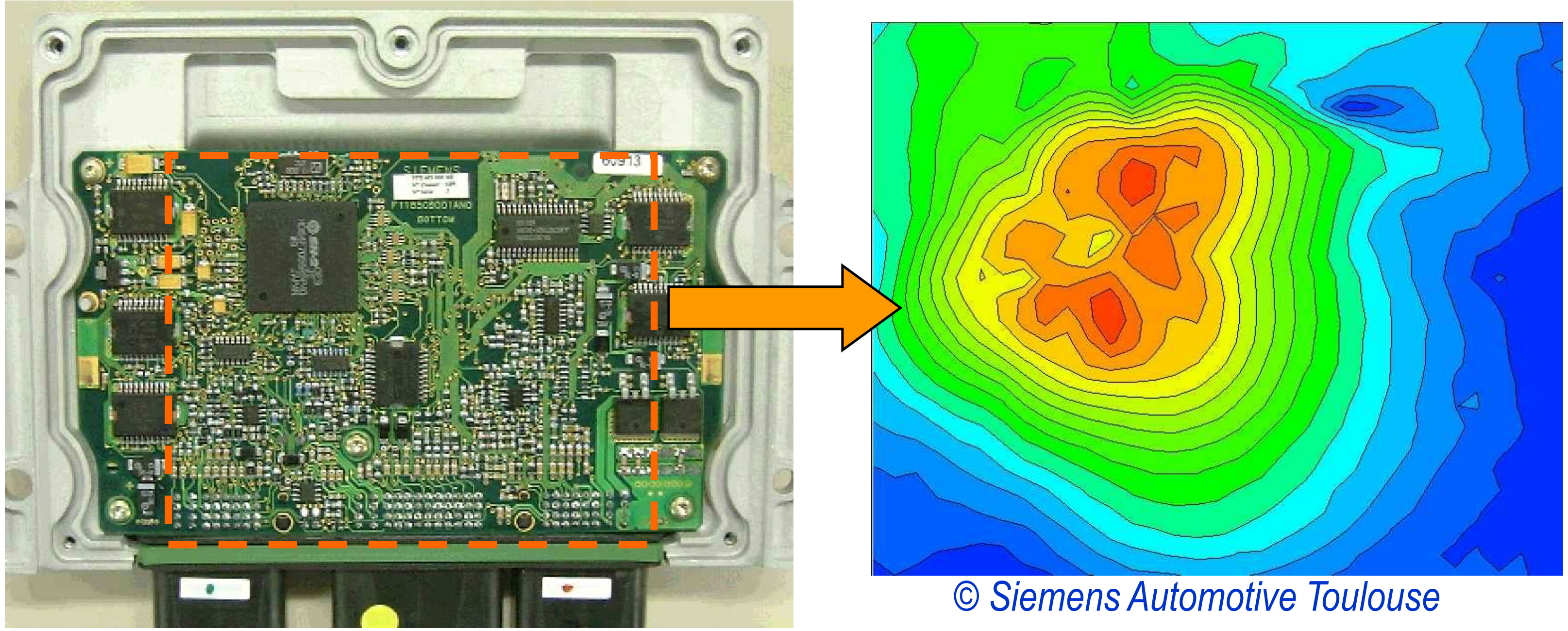
Outline

- Introduction to EMI and RFI for High-Speed Systems
- Trend of Wireless Communications and Automotive Development
- Platform Noise Impact on Throughput
- EMI Analysis of Key Components in Mobile Device
- Application of Noise Budget and Analysis Model for System Integration
- Conclusion

Equipment designers want to predict EMC before fabrication



© Siemens Automotive Toulouse

- Most of the time, EMC measurements are performed once the equipment is built.
- No improvements can be done at conception phase.
- Predict EMC performances → IC, board, equipment optimizations
- However, need of non-confidential IC models (black box models)

Application Concept of Noise Budget

Interference Source

↓

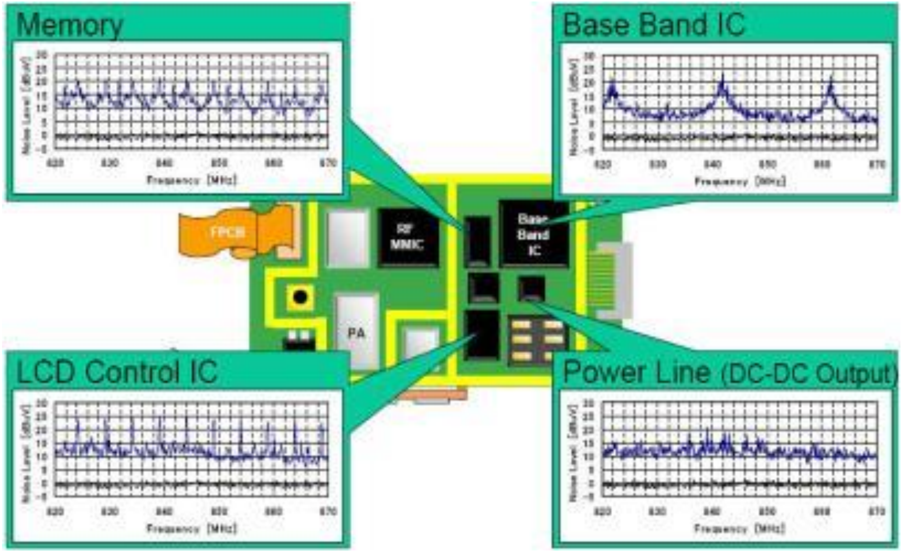
Interference Frequencies

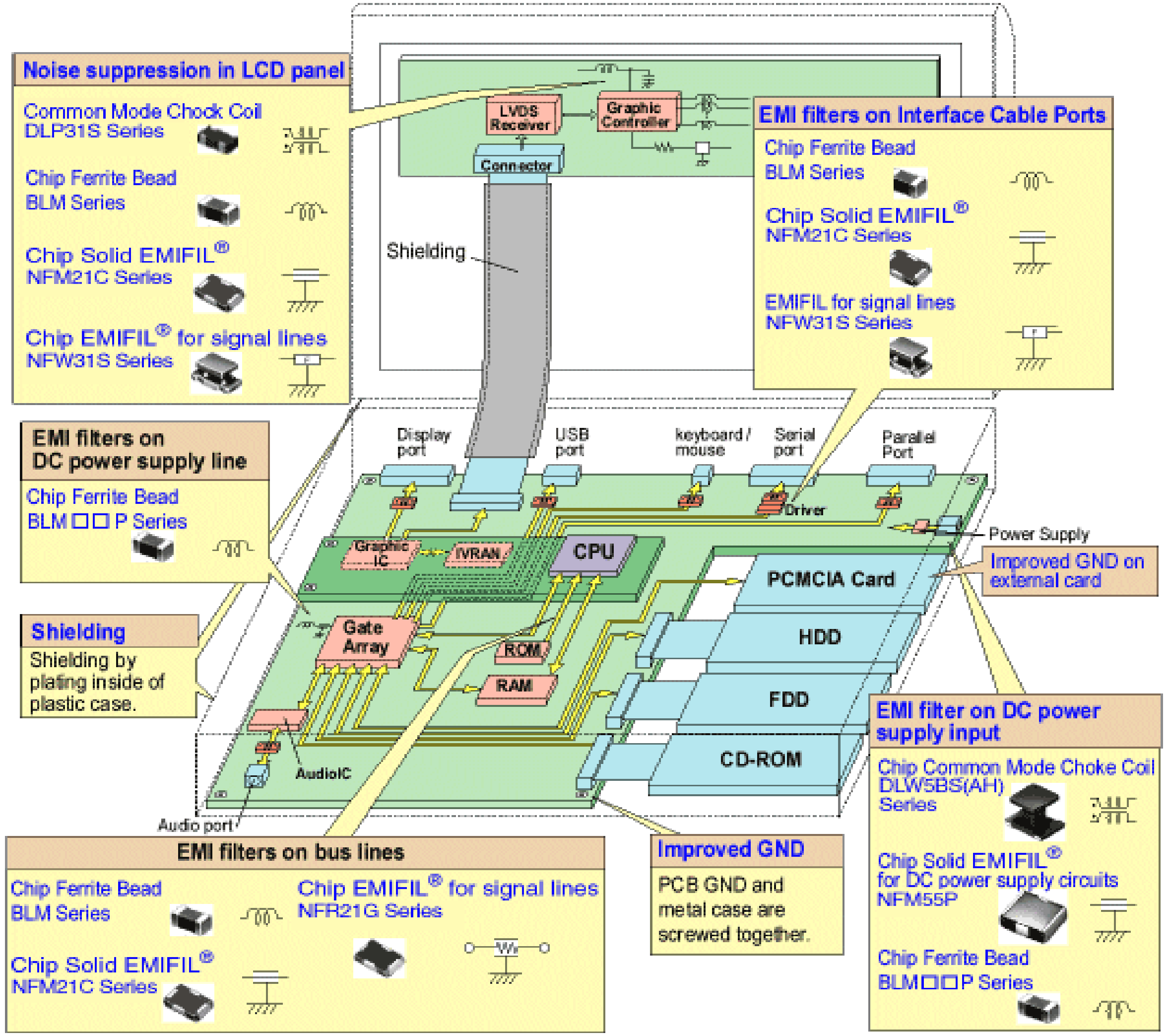
↓

Interference Position

↓

Communications Performance



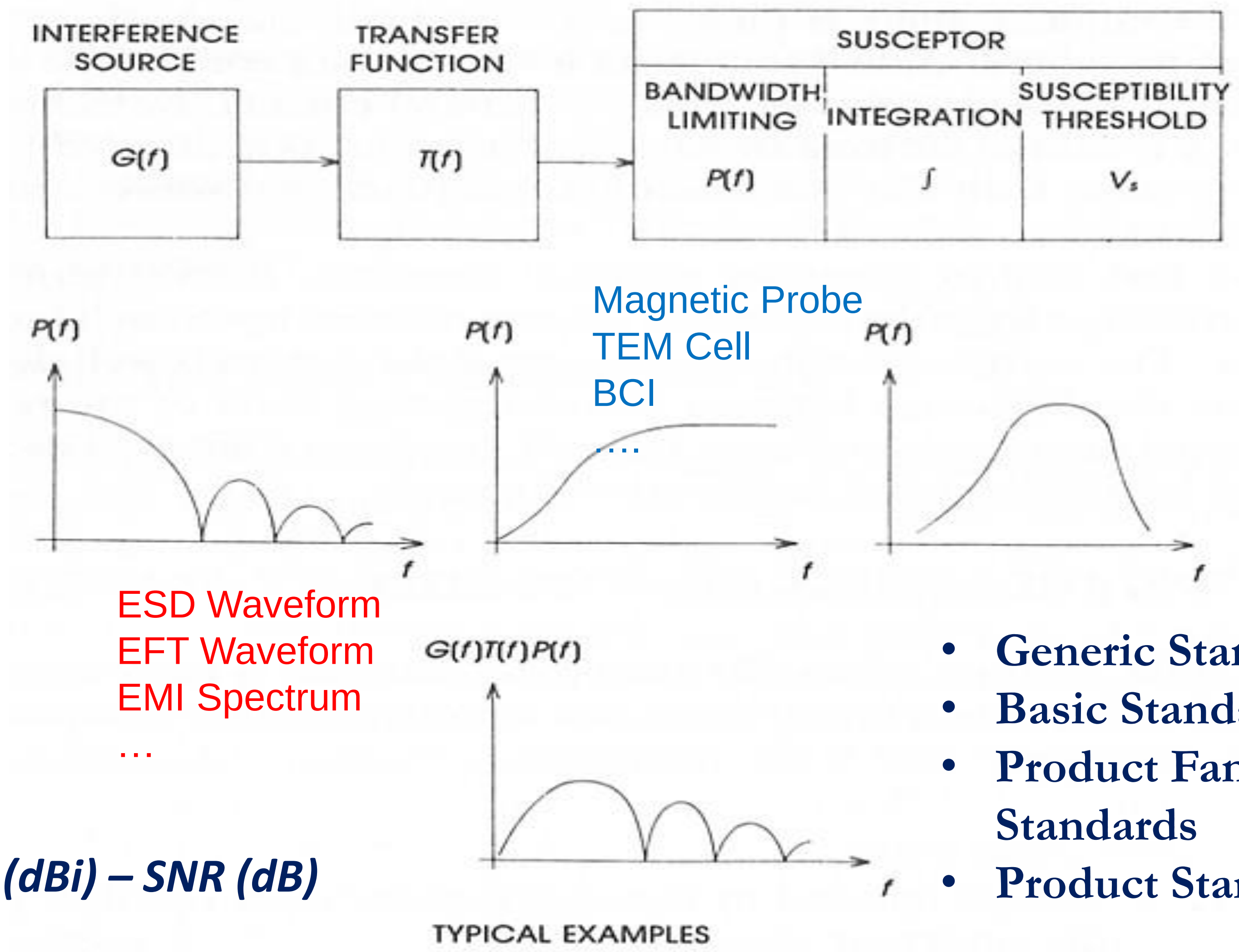


Predict system-level performance from component-level information

Old Approach: Put the components in a “typical” system and measurement the system performance.

Better Approach: Fully characterize the components themselves, then model system behavior.

Compatibility Analysis Model



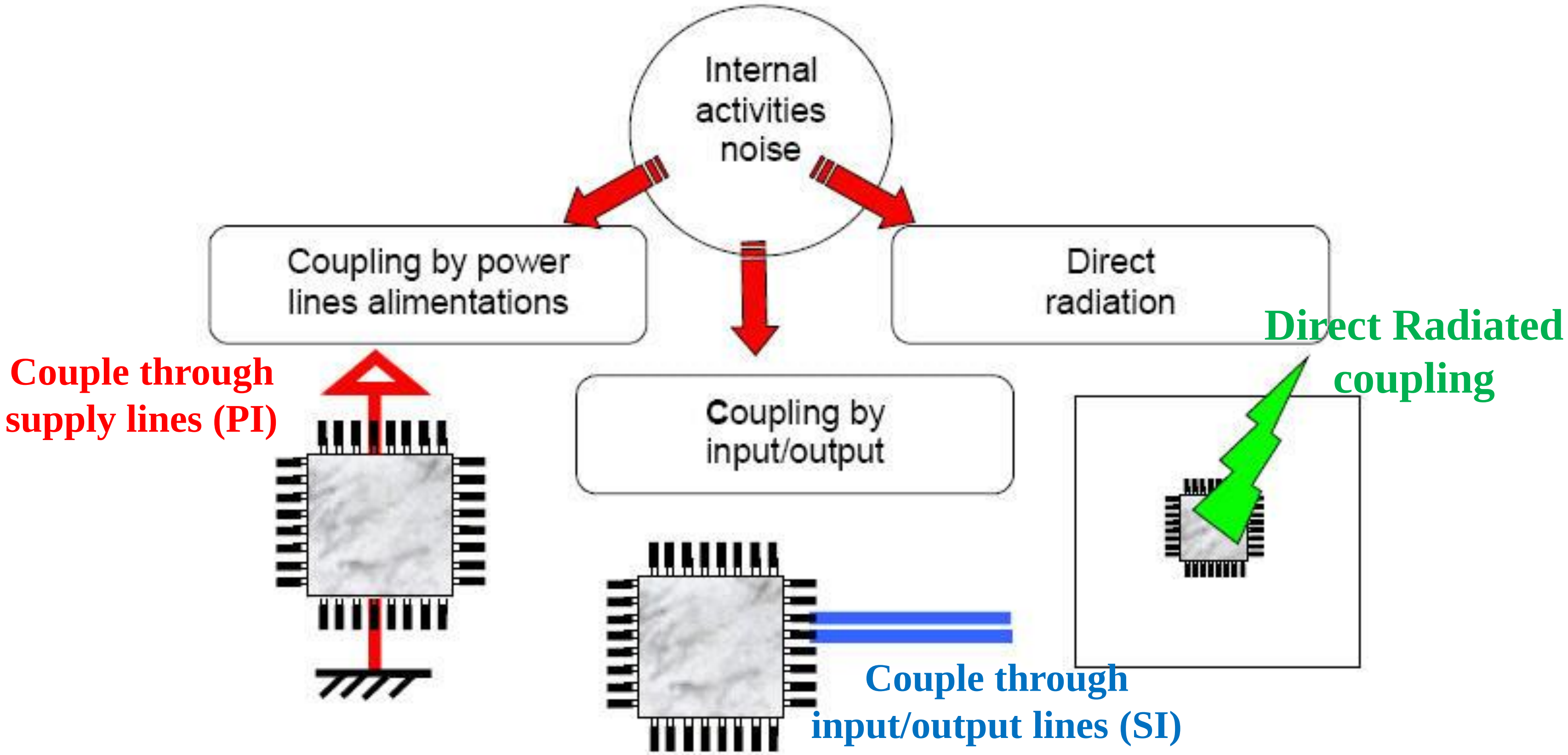
Magnetic Probe
TEM Cell
BCI
....

ESD Waveform
EFT Waveform
EMI Spectrum
...

N_{Limit} (dBm) =
S_M (dBm) + G_A (dBi) – SNR (dB)

- Generic Standards
- Basic Standards
- Product Family Standards
- Product Standards

Mechanisms for ICEM parasitic emission

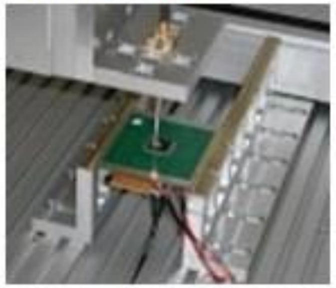


Component measurements should characterize the source in order to build models that can be used at the system level. ***Otherwise, they are mostly useless!***

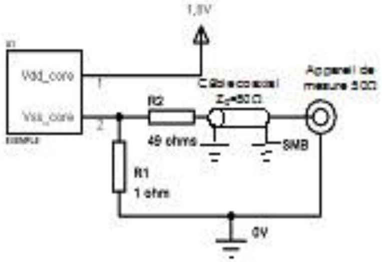
Standard methods for emission characterization of ICs

IEC 61967-2: TEM and GTEM, 1 – 18 GHz

IEC 61967-3 Technical specification: Near field scan, 1-5GHz



IEC 61967-4:
1/150 ohms, 1 GHz



IEC 61967-5:
WBFC, 1 GHz

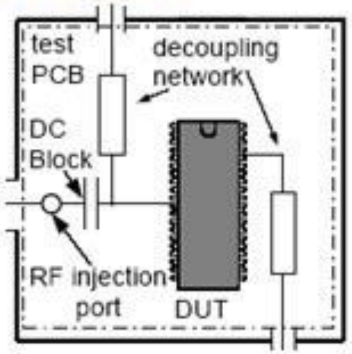
IEC 61967-6
Magnetic field probe, 1GHz

IEC 61967-8:
IC-Stripline, 3 - 6 GHz

Standard methods for immunity characterization of ICs

IEC 62132-3
(BCI, 1 GHz)

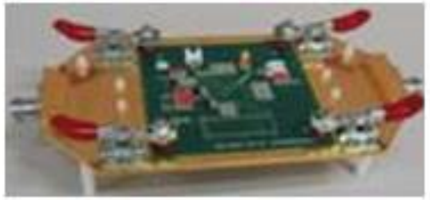
IEC 62132-4
(DPI : 1 GHz)



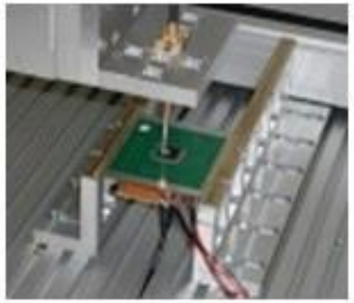
IEC 62132-2
(TEM - GTEM : 1 / 18GHz)

IEC 62132-5
(WBFC, 1 GHz)

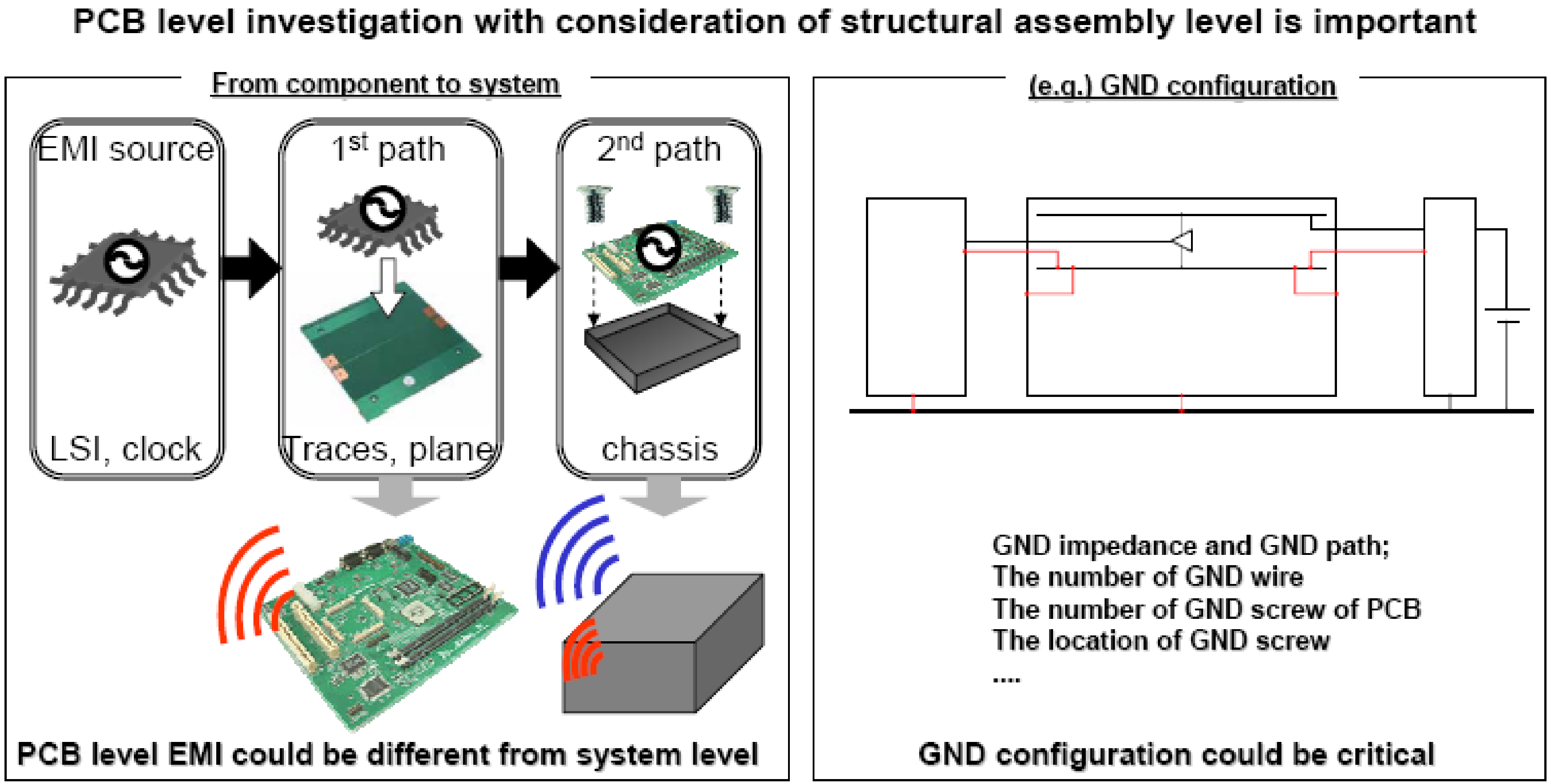
IEC 62132-8
(IC-Stripline, 3/6 GHz)



IEC 62132-9
(Near-field scan, 1/5 GHz)

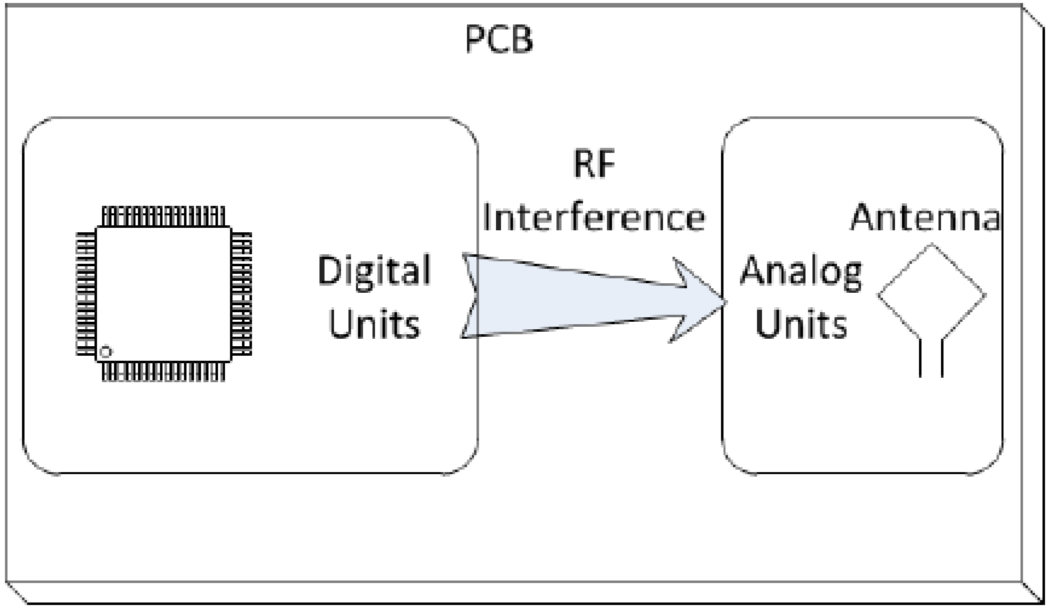


Intra-System EMI and PCB level EMC



System level EMC must be taken care at component level

Pre-Layout Placement Design

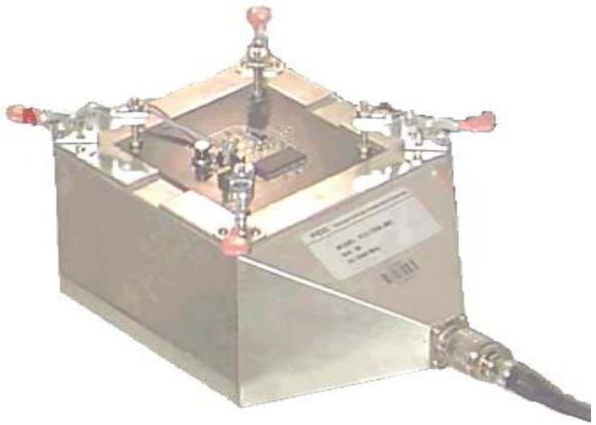


- **Major players in this interference problem**
  - Digital IC – Noise Source ⇒ a library model
  - RF Interference – Coupling Path ⇒ modeling or measurement
  - RF antenna – Victim ⇒ a library model

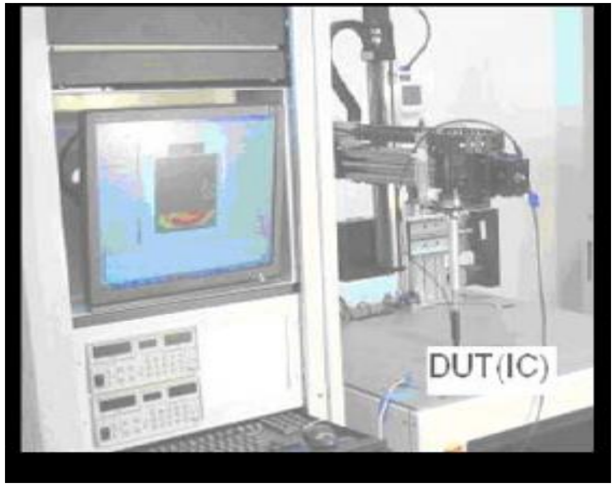
⇒ Noise voltage at RF receiver can be quickly estimated

Two Source Reconstruction Approaches

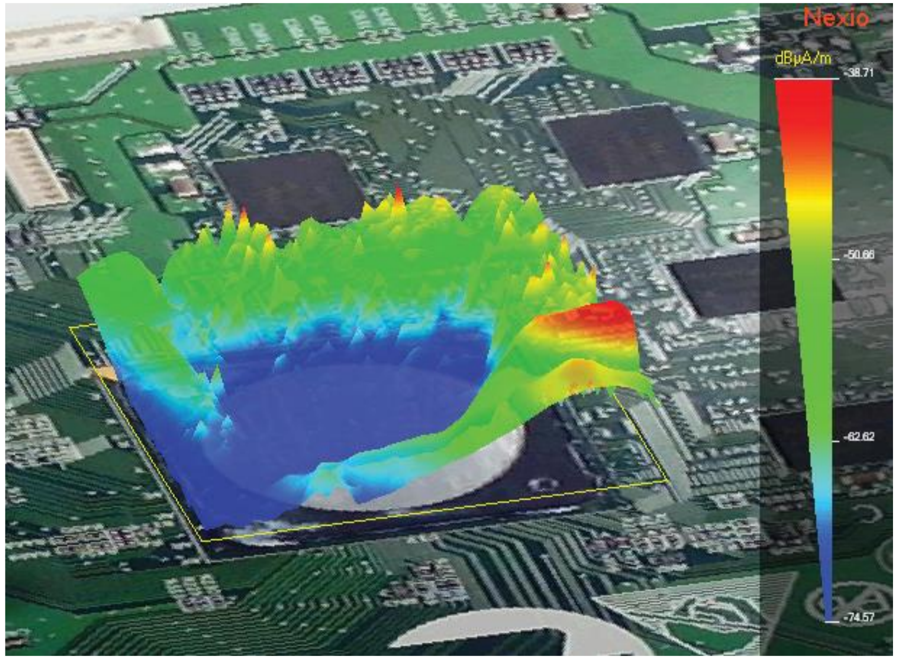
- **Source reconstruction based on TEM cell measurement**
  - Test PCB
  - Dipole extraction from TEM measurement
  - Correlation to far-field measurement



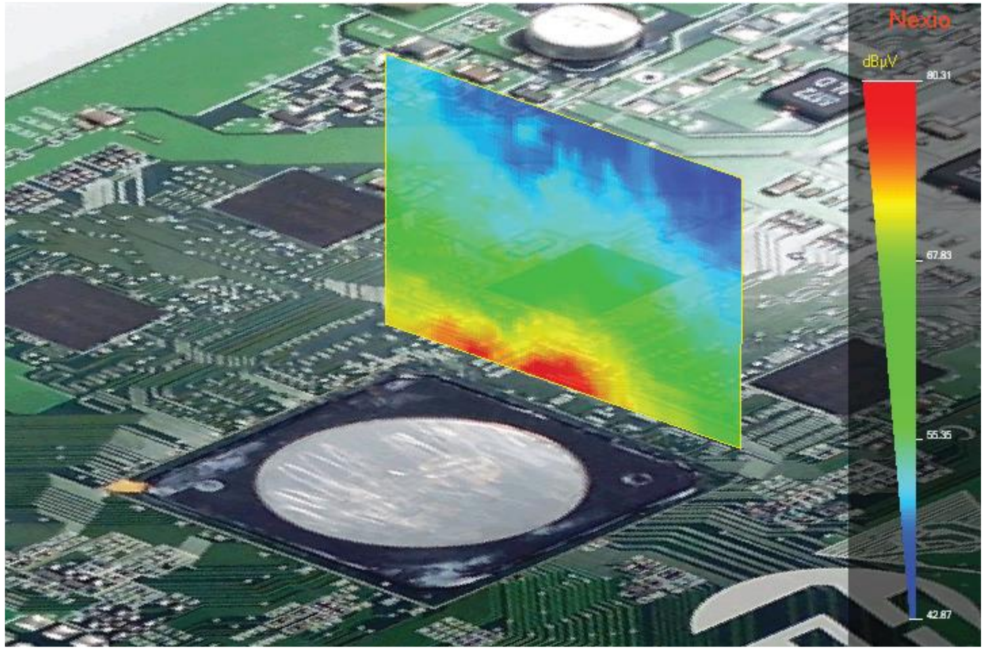
- **Source reconstruction based on near-field scanning measurement**
  - Calculation of equivalent dipole array from near-field scanning
  - Reconstruction of fields at any location from dipole array.



Horizontal and vertical magnetic near field scan of a SoC



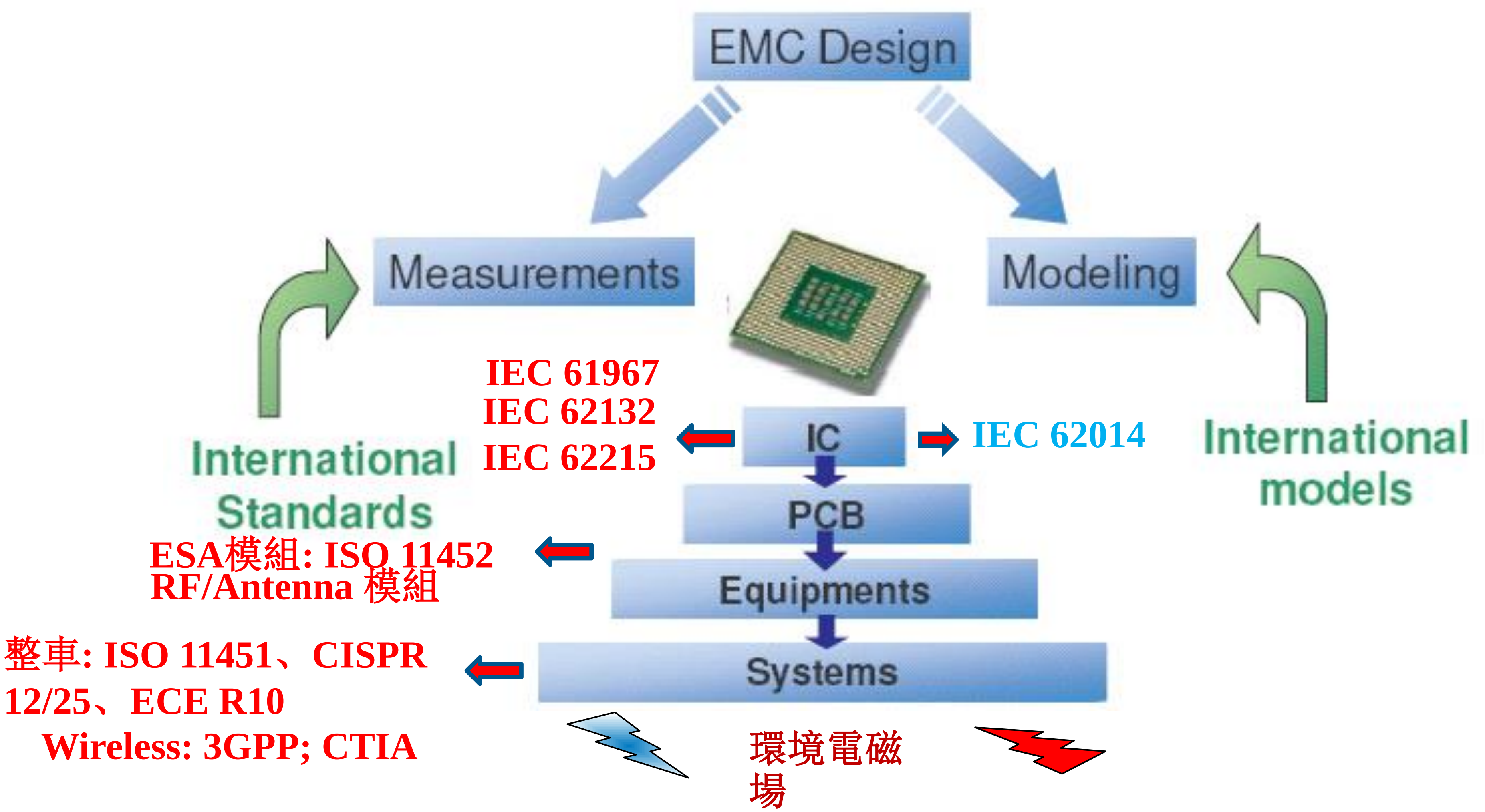
(a) 2D horizontal scan



(b) Vertical scan plot from a full 3D near-field scan

(Nexio from 2016 IEEE Electromagnetic Compatibility Magazine – Volume 5 – Quarter 1)

Hierarchy Measurement and Modeling for EMC



SIMULATION VS. MEASUREMENT

Characteristic	Simulation	Measurement
When used in design process	Early on	Near the end
Physical requirements	Simulation software	Oscilloscope/VNA/TDR, design prototype
Uses	• Understanding system margins • Making design tradeoffs • Verification of the design	Verification of the prototype hardware
Expertise required	Little to extensive	Medium to extensive
Limitations	• Everything must be properly modeled • Not all effects can be included • Software makes assumptions	• Affects circuit performance • Needs places to probe • Makes assumptions
Advantages	• No need for physical prototype • Find and fix problems before prototype • Can probe anywhere • Easy to analyze design tradeoffs • Easy to analyze potential fixes to problems	• Includes most effects • Close to reality

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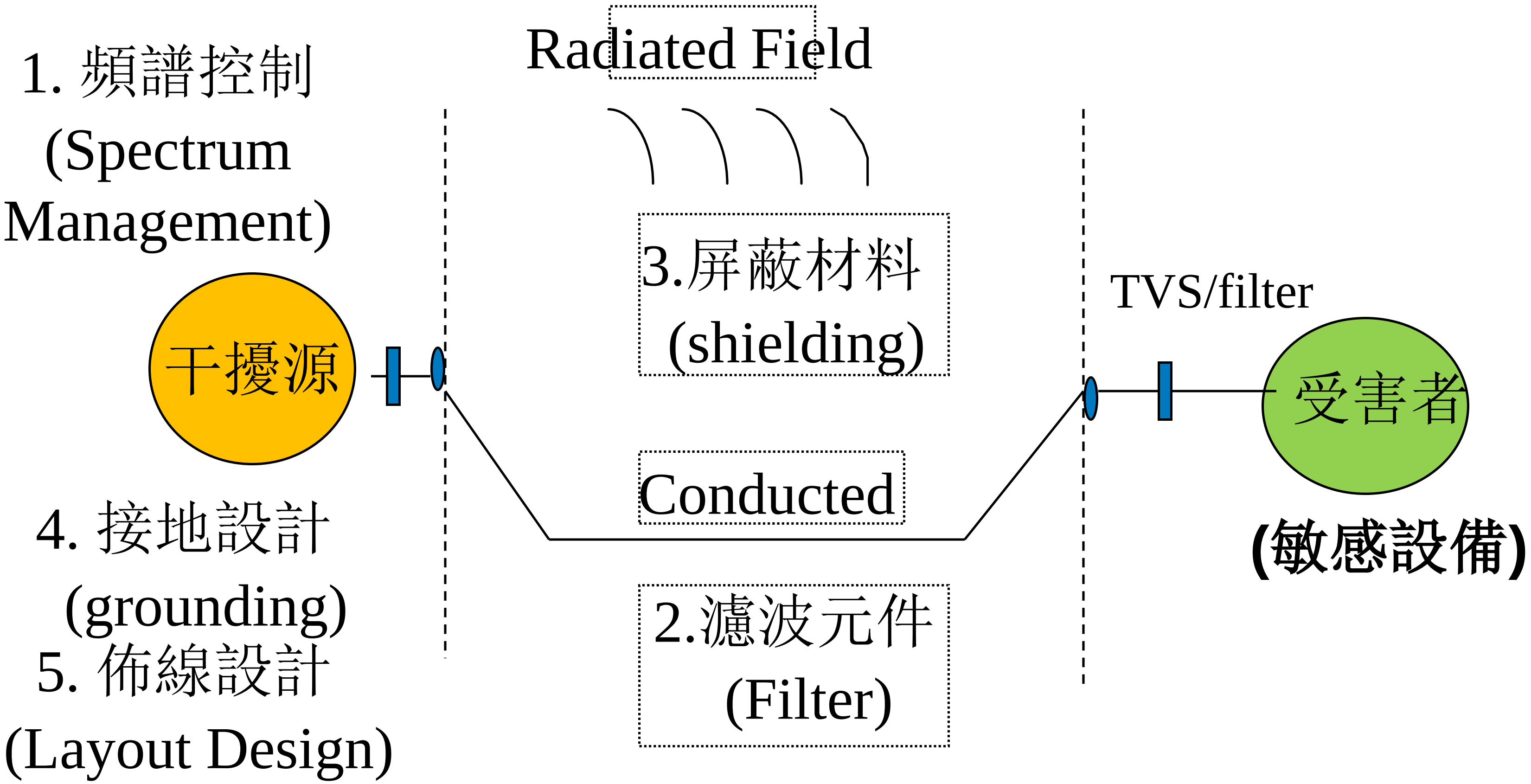
EMC Design Strategies



Emerging Platform Trends

- **Ultra-mobile, ultra-compact and consumer platforms will drive *pervasive changes* in chip-level RFI & EMI just as they are doing to chip power and packaging.**
  - More radios and RF coexistence
  - Pocket-sized form factors
  - Increasing data rates & performance requirements
  - Usage driven performance criteria
  - Pressure to eliminate shields & reduce size will be *intense*.
  - SiP's don't allow for board-level fixes. Silicon *must* be right.
  - No time for multiple design spins.

EMC Challenge and Development for Future

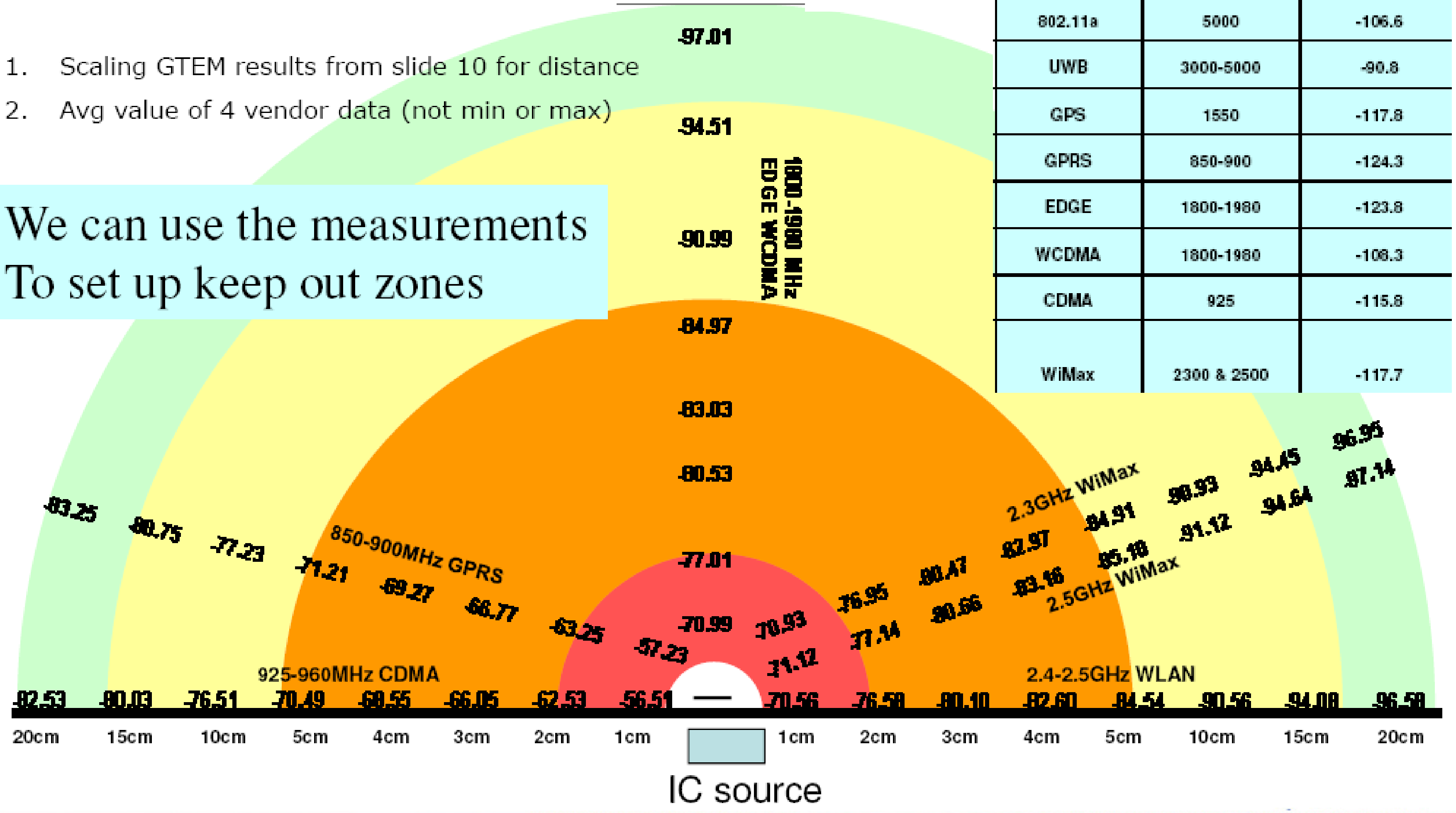
- ***From Inter-System Regulations Requirement***
  - Regulatory Design: SAR、HAC、RF、RSE、AGPS (Debugging with Antenna Design、RF Absorber、 shielding and filtering)
  - Full Automobiles
- ***Through Intra-System Coupling Analysis***
  - OTA Performance Requirement for Wireless Communications (Edge of Link)
  - MIMO (Throughput)
  - Automobile Modules
- ***To Silicon Chip and Package Level Request***
  - Noise budget for IC EMC measurement
  - IC EMI Noise Modeling
  - S/N Prediction (Placement、 Coupling)

Isotropic Radiator Concept for Noisy IC Placement

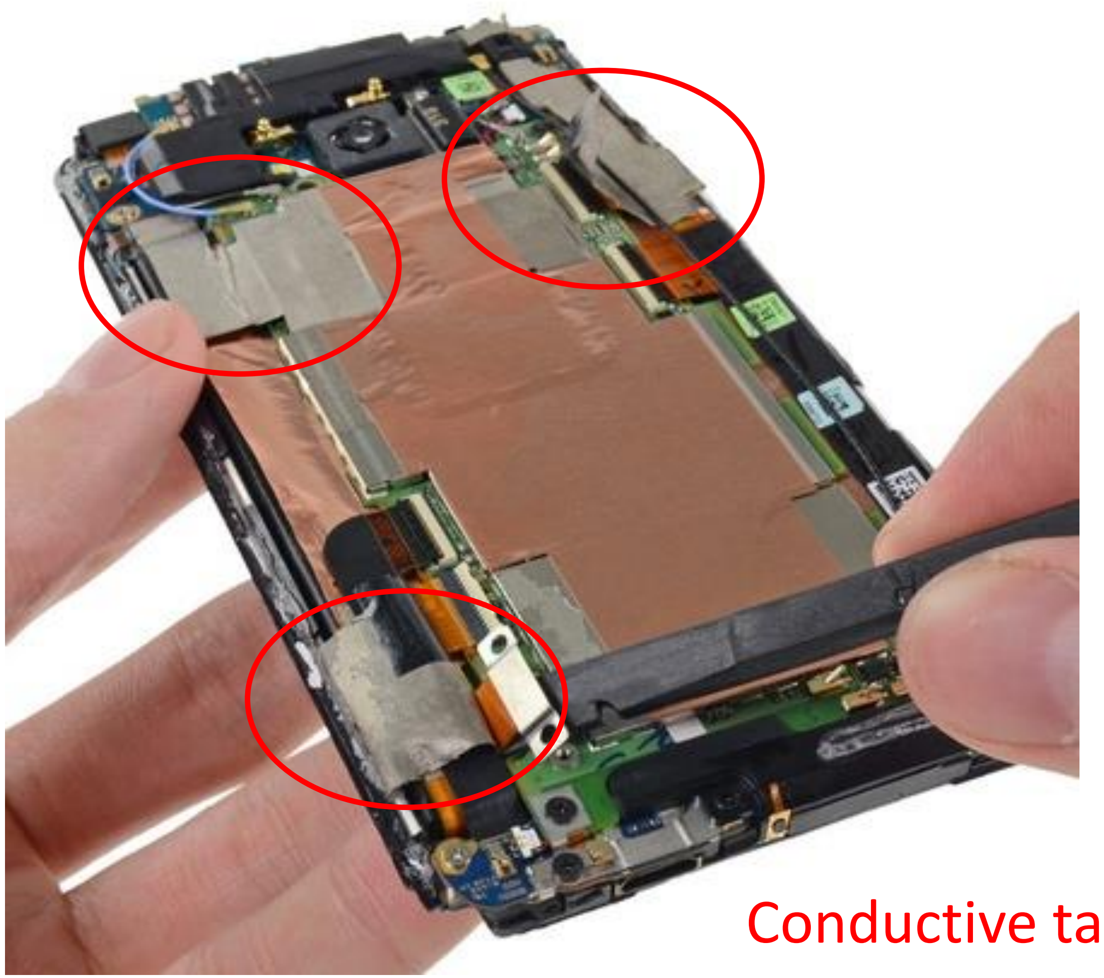
1. Scaling GTEM results from slide 10 for distance
2. Avg value of 4 vendor data (not min or max)

We can use the measurements
To set up keep out zones

Protocol	Frequency (MHz)	Receiver Sensitivity (dBm)
802.11b/g	2400	-105.8
802.11a	5000	-106.6
UWB	3000-5000	-90.8
GPS	1550	-117.8
GPRS	850-900	-124.3
EDGE	1800-1980	-123.8
WCDMA	1800-1980	-108.3
CDMA	925	-115.8
WiMax	2300 & 2500	-117.7



Before Components EMC Adoption



Conductive tapes everywhere

After Components EMC Adoption

Solutions are on component side

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