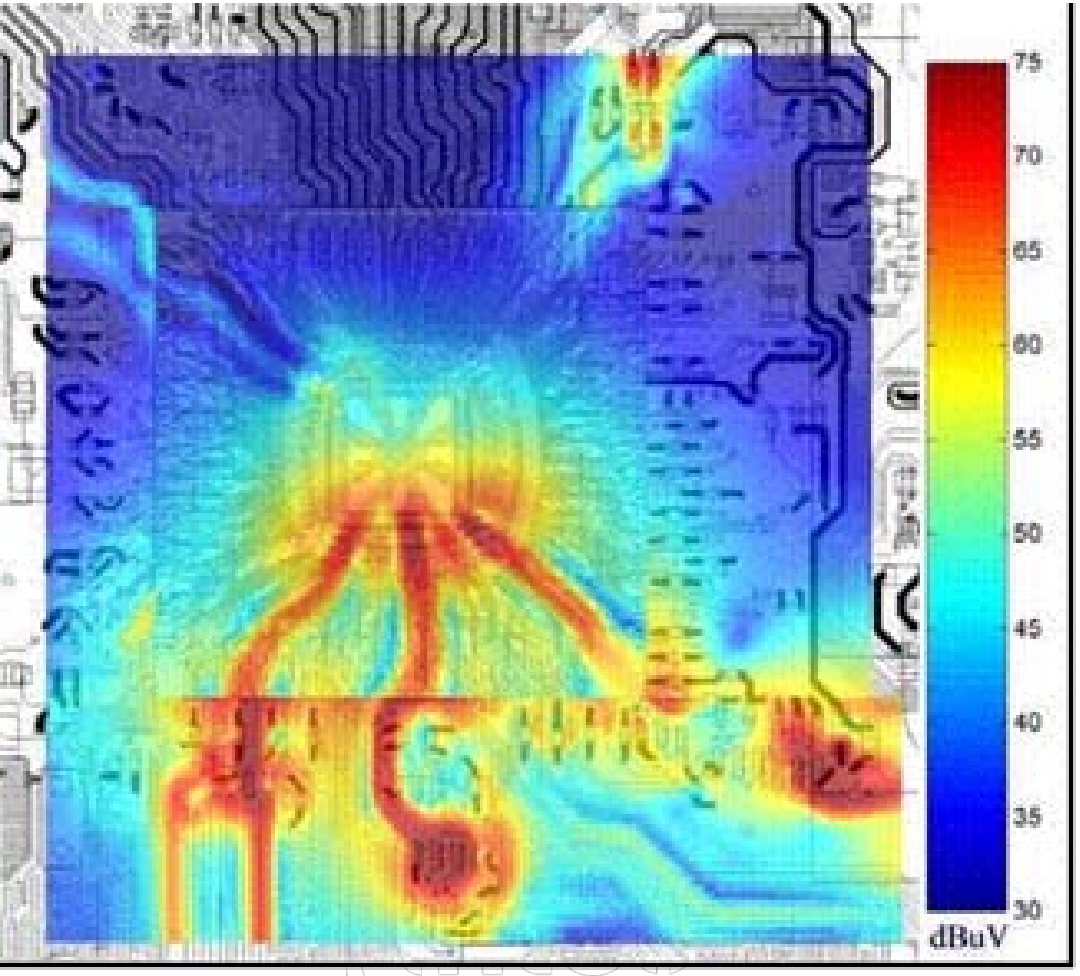
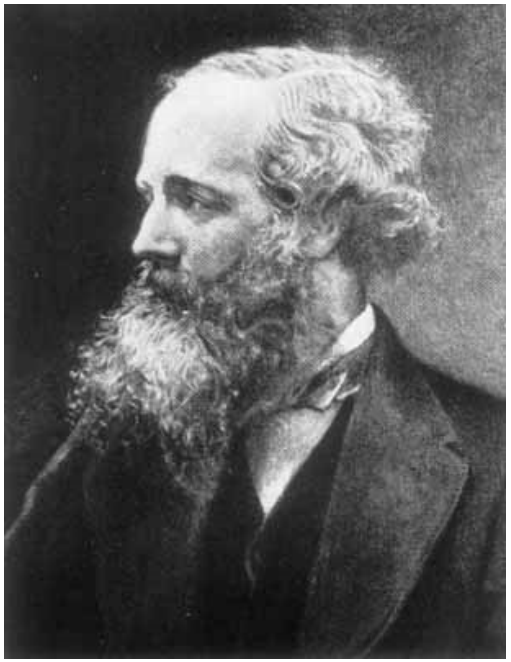


Near field scan over IO control hub

Platform Interference: Scope, Method, Mitigation

Kevin Slattery

Intel



Wireless System EMI: A New Paradigm?

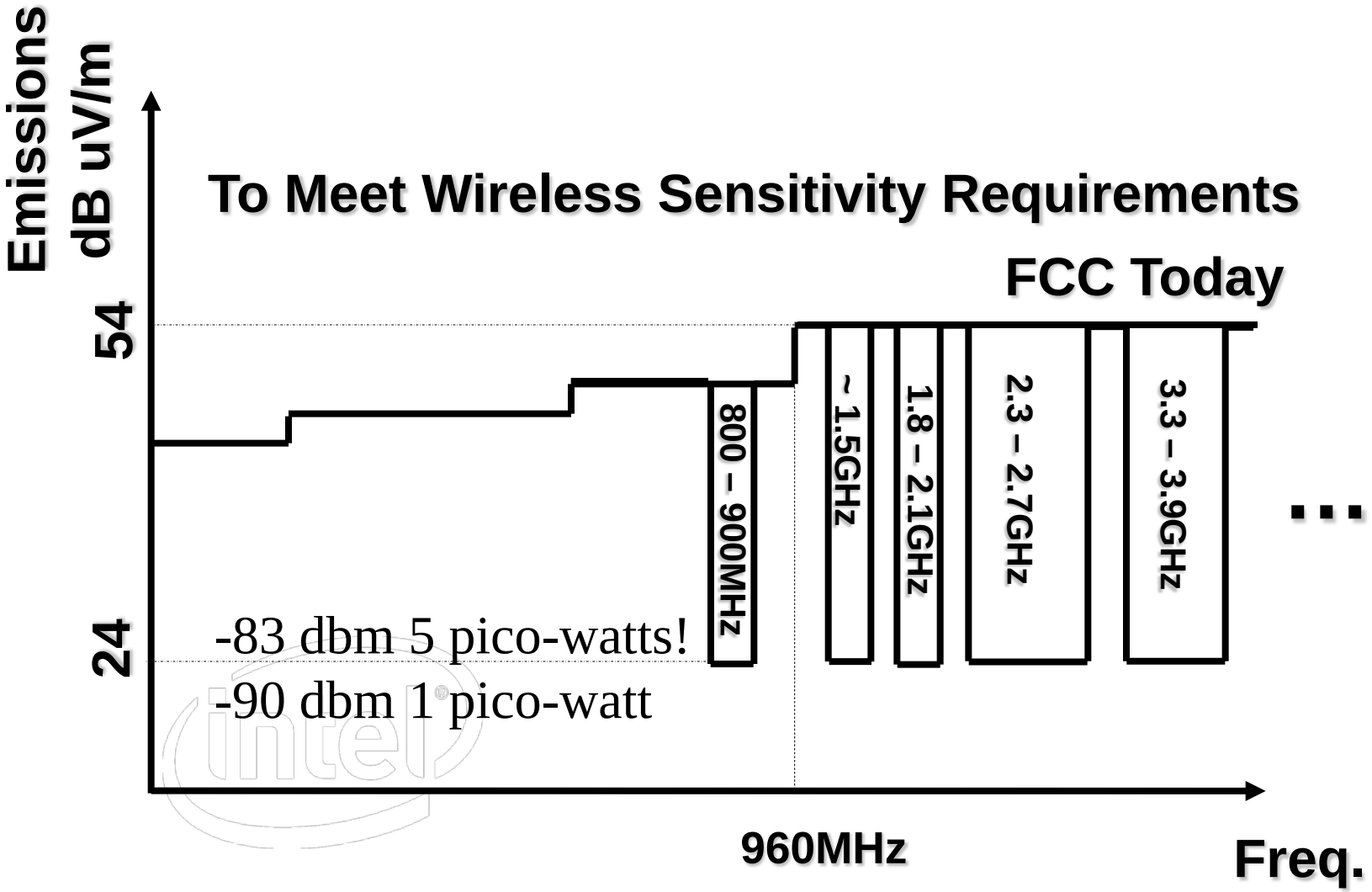
With the advent of mobile computing, wireless communication has become an integral part of the compute platform. Who would now consider buying a laptop without wireless? At the same time, what were once simple communication devices such as cell phones are now adding functions which require subsystems ordinarily associated with compute devices. So what's the big deal? The problem is these devices were never intended to coexist. Communications devices have not been designed with high speed digital logic in mind. High Speed digital logic has never included communications as a design vector. The end result is that these devices don't work well together and much shoehorning is currently undertaken to make them cohabit in the same device. That shoehorning generally incurs costs in terms of product delays and additional mitigation solutions. It is a sobering thought that 3dB of noise can reduce the performance of your communications system by 50%. It is even more sobering that 20 or even 30dB of noise is common on some devices. This talk has two main intentions:

1. A discussion of what RF interference is
2. A reference source for identifying noise related issues and mitigating them in your current or future system design

Setting the Scene

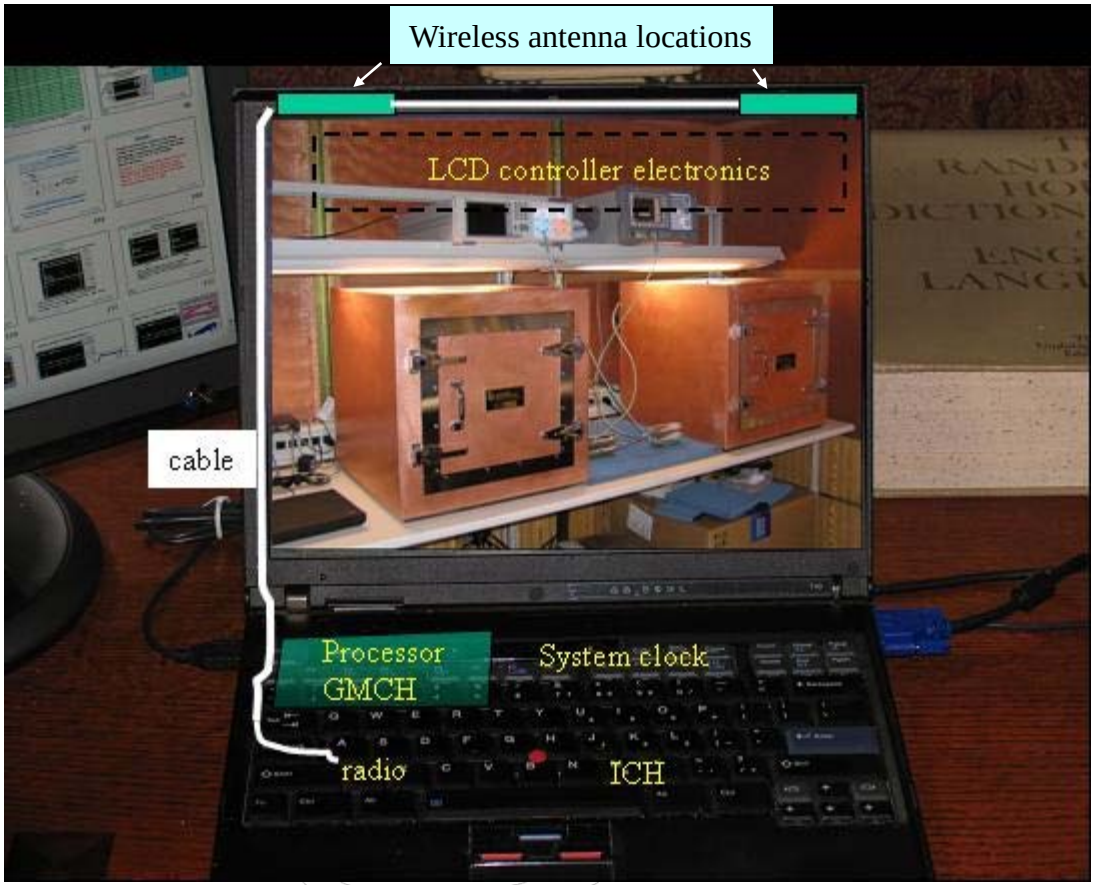
- Today EMI/EMC is essentially regulation driven (FCC, CISPR, CE Mark…)
- Regulations are based on machine to machine interference avoidance
- Wireless / RF and EMC have been separate and distinct worlds
- No real consequences of EMI emissions in wireless bands.
- Until now…

The Grand Challenge

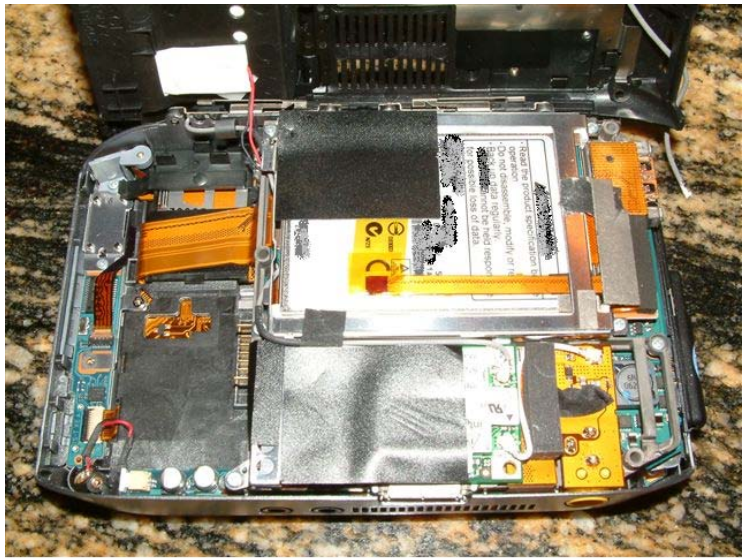


30dB reduction in Limits not realistic!

Platform RF Interference:

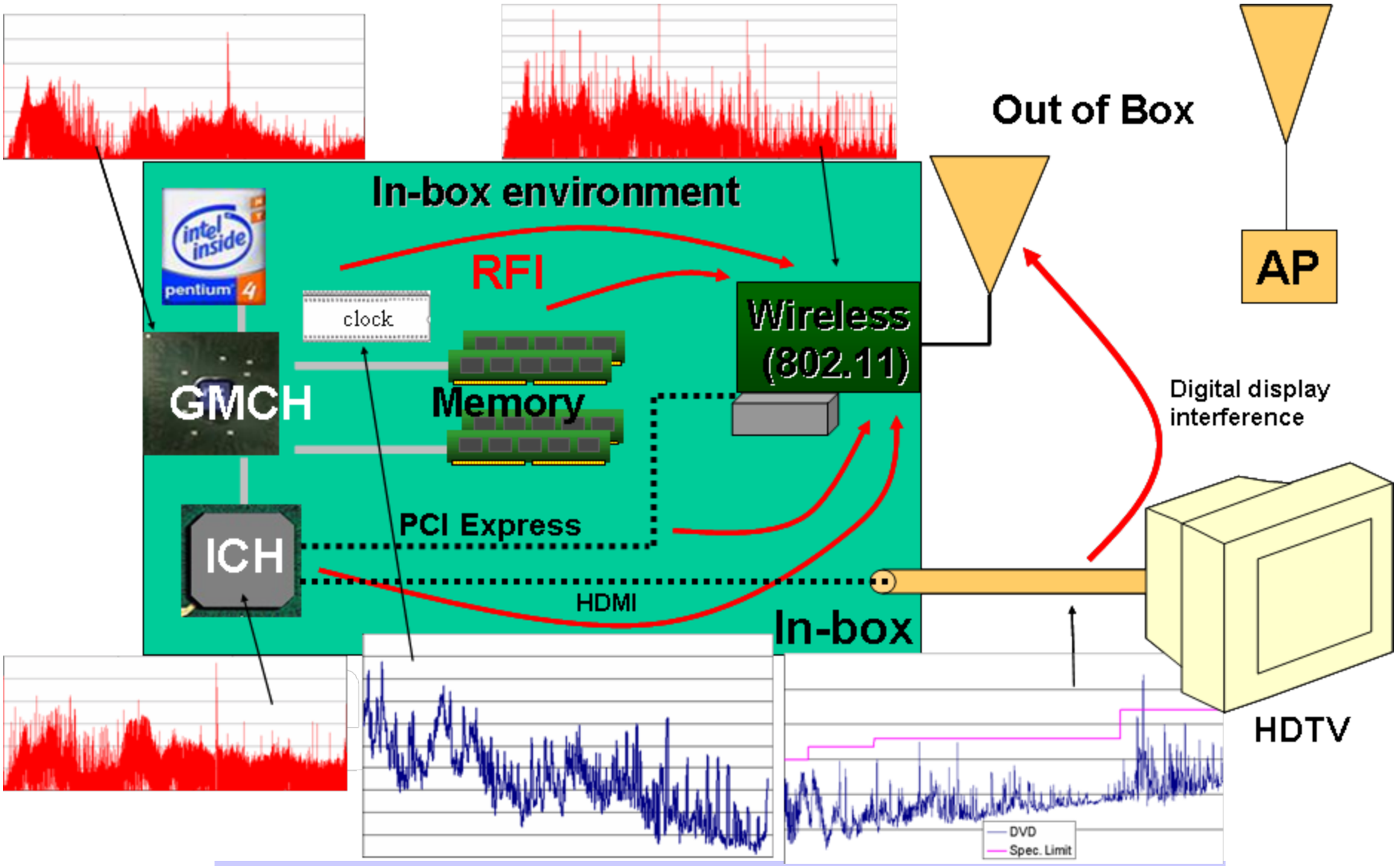


What "solutions"
Sometimes look like



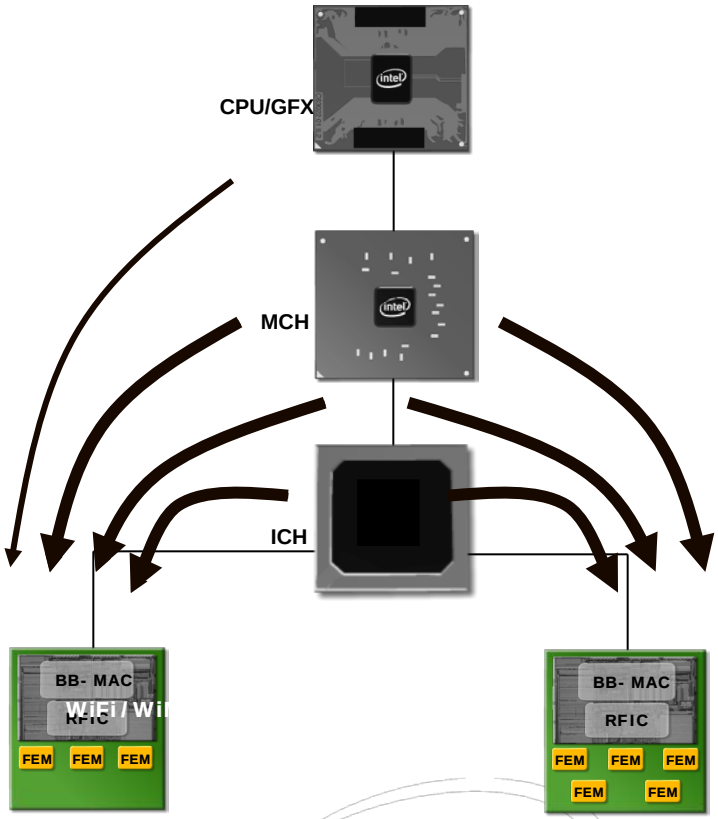
The wireless is embedded in a coupled electromagnetic environment

Platform RF Interference:



Different signal structures produce different spectra

Problem Statement (Trends) – circa 2005 Today, '09 and Beyond



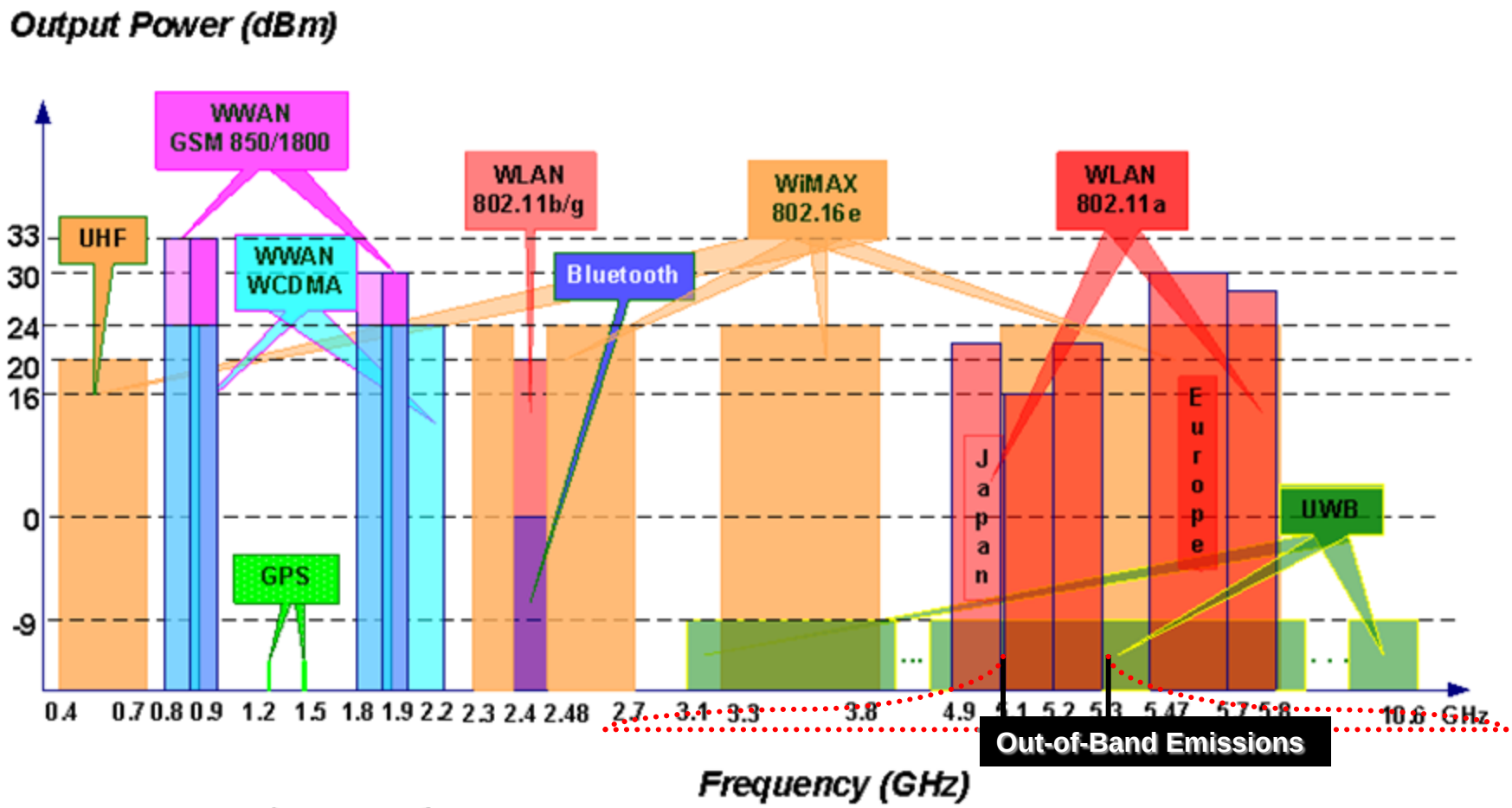
Platform RF Interference severely impacts wireless performance.

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**

Issue: Platform Noise is a problem today and will get worse if we did nothing

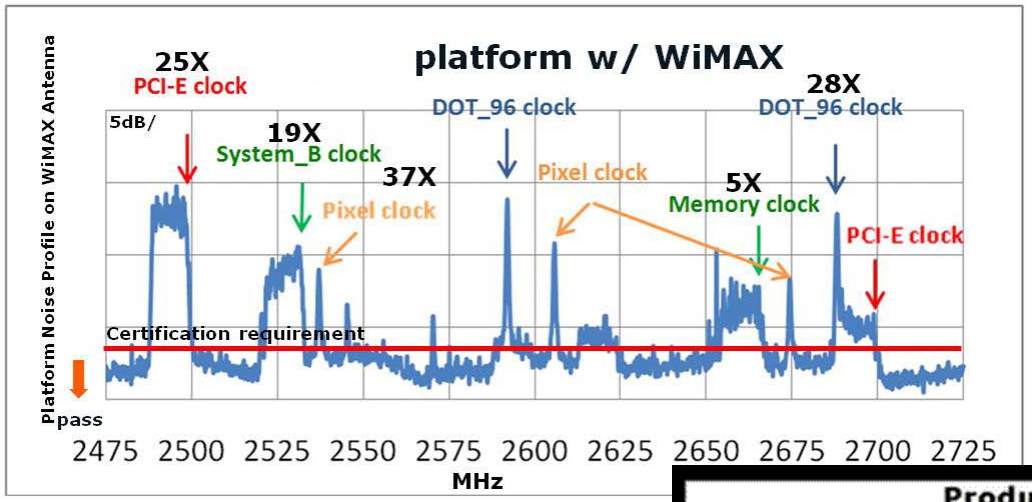
Frequency Spectrum Complexity Growing



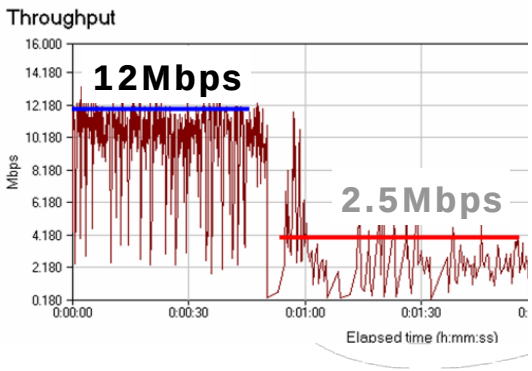
RF Interference from Frequency Overlap, Out-of-Band Emissions & Receiver Saturation

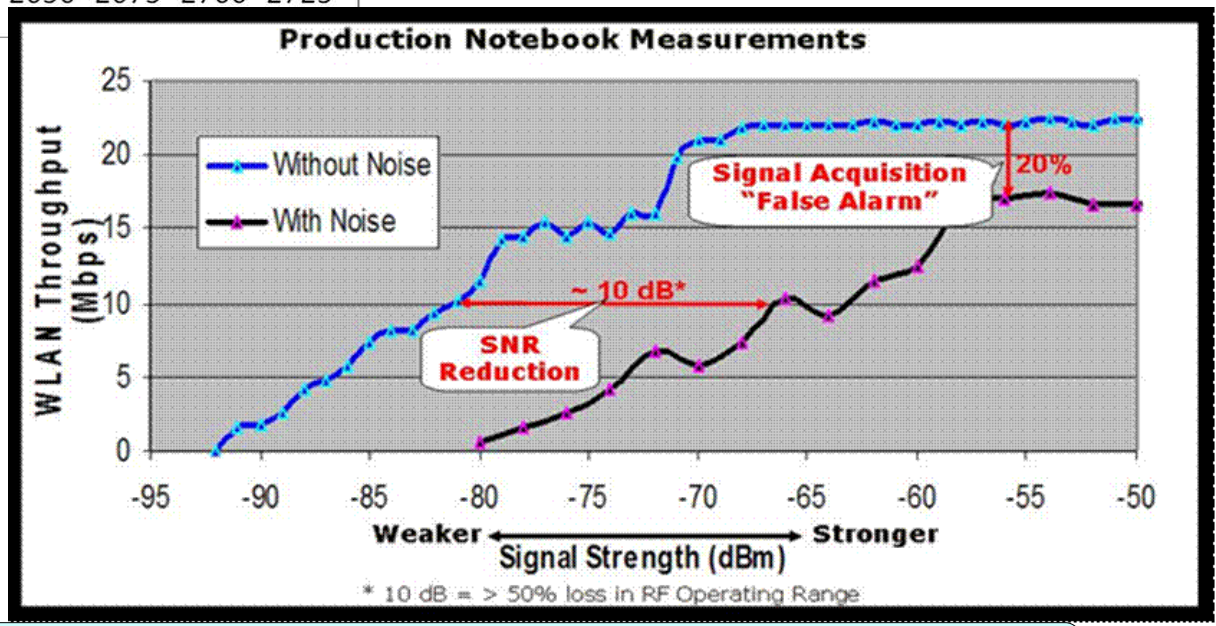
Why must we address RFI?

More licensed radios and high frequency digital functions must coexist in smaller form factors



- Platform noise kills platform wireless receivers.
- Results in degraded performance and certification failure.
- Problems increase as # of radios grows

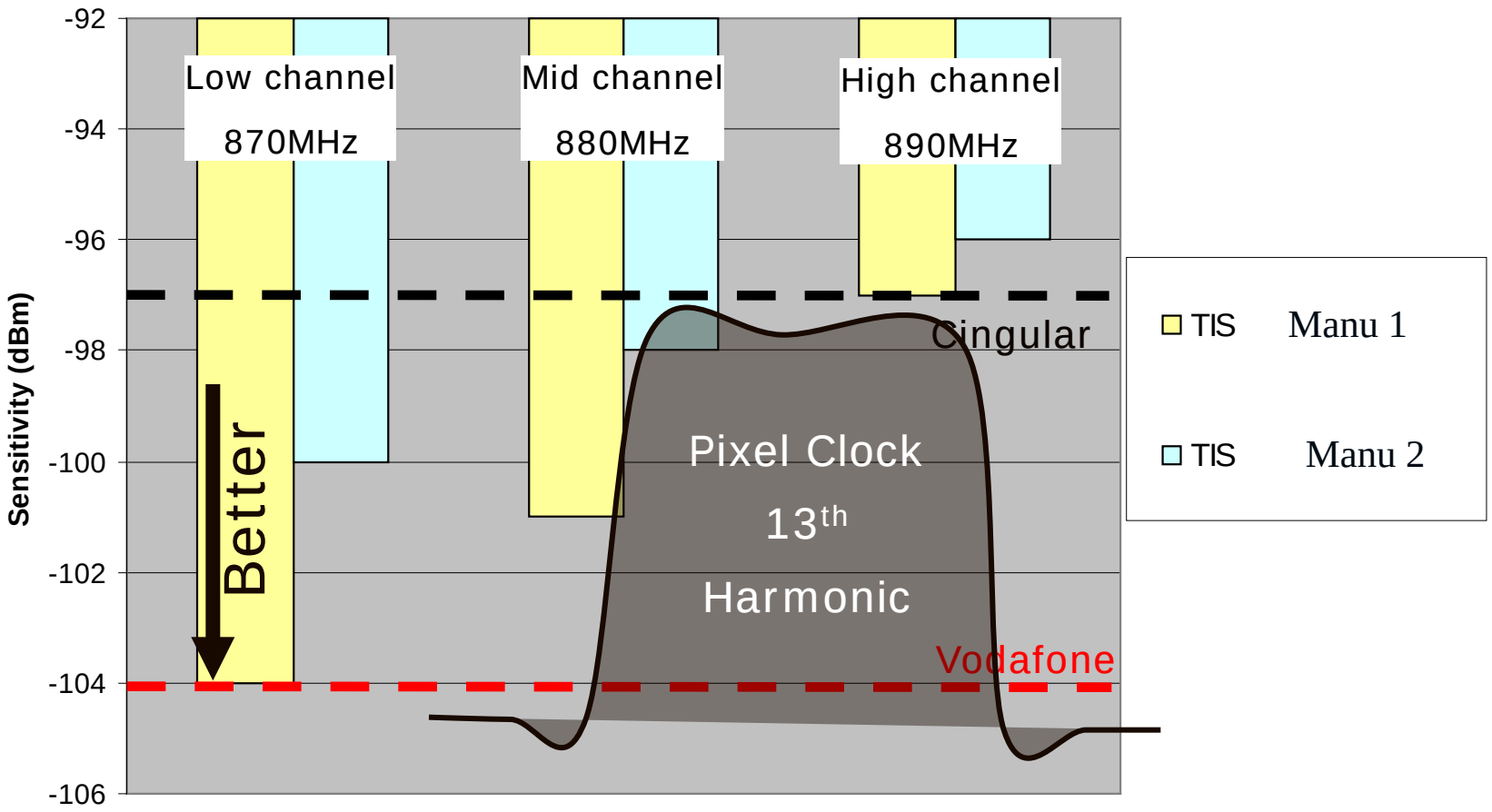




>50% Range Reduction due to Platform Noise

Problem Statement (Example) - – circa 2005
WWAN / WiMax Carrier Certification - Requirements

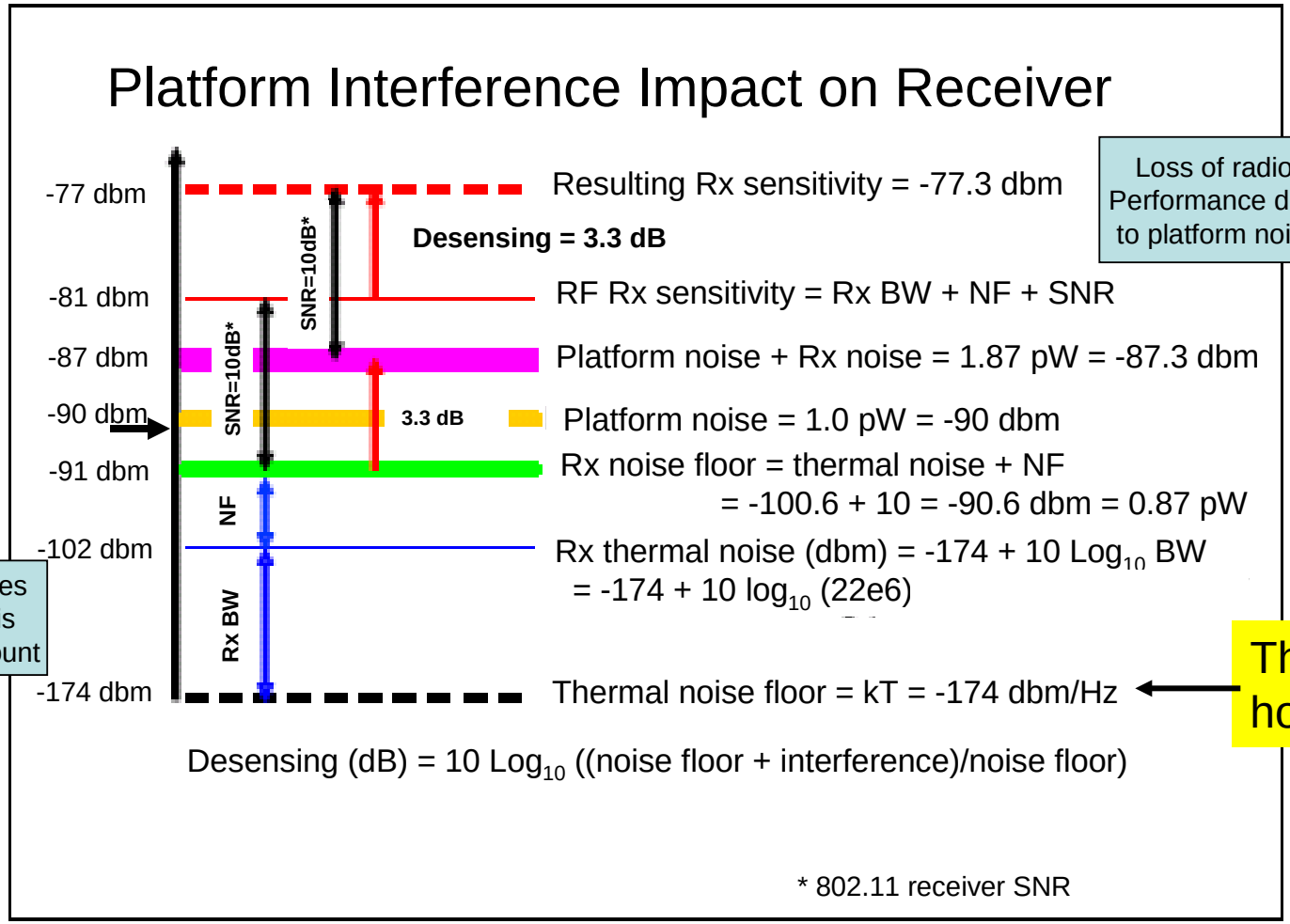
2 cell phone TIS Measurements on a platform



Carriers Dictate Performance Requirements.

You don't pass in the intended system – you don't ship!

Determining loss of receiver sensitivity in the presence of noise



	WI-FI		
Noise Calculation	802.11b	802.11g	802.11a(5GHz)
Thermal noise	-173.8dBm	-173.8dBm	-173.8dBm
Channel BW	73.4dB	73.0dB	72.2dB
Thermal noise @ BW	-100.4dBm	-100.8dBm	-101.6dBm
Noise Figure	5.0dB	5.0dB	5.0dB
Margin	0.0dB	0.0dB	0.0dB
De-sensitization	10.0dB	10.0dB	10.0dB
Allowable Interference Level (dBm)	-105.4dBm	-105.8dBm	-106.6dBm

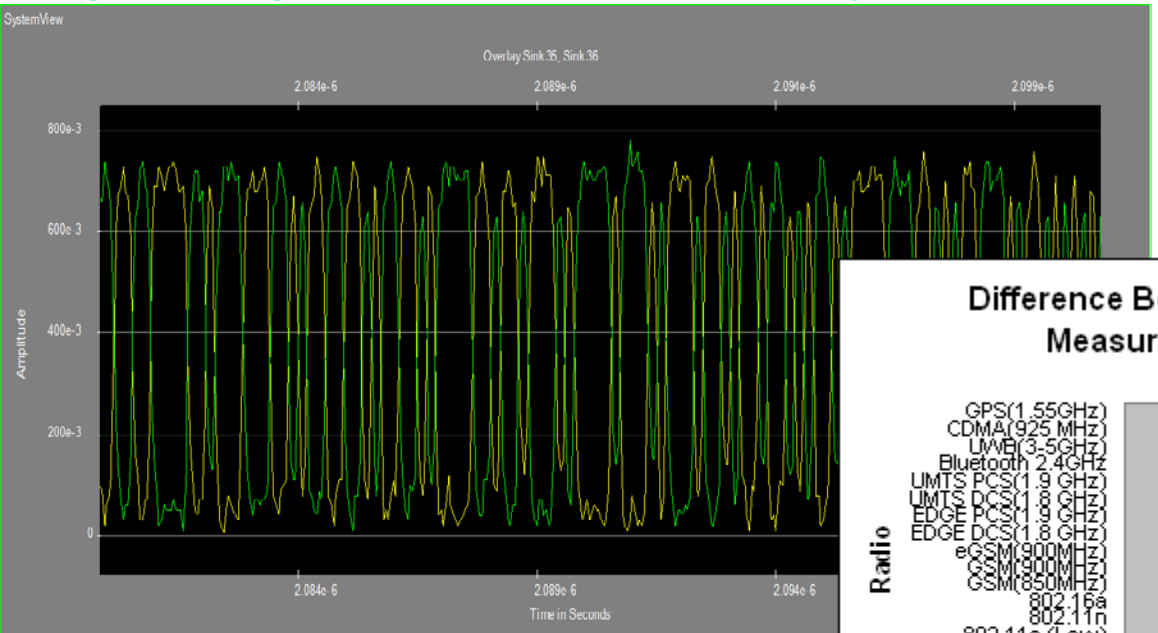
	WPAN		Satellite
Noise Calculation	Bluetooth(2.4GHz)	UWB(3-5GHz)	GPS(1.55GHz)
Thermal noise	-173.8dBm	-173.8dBm	-173.8dBm
Channel BW	60.0dB	87.0dB	63.0dB
Thermal noise @ BW	-113.8dBm	-86.8dBm	-110.8dBm
Noise Figure	15.0dB	6.0dB	3.0dB
Margin	0.0dB	0.0dB	0.0dB
De-sensitization	10.0dB	10.0dB	10.0dB
Allowable Interference Level (dBm)	-108.8dBm	-90.8dBm	-117.8dBm

	GPRS (2.5G)	EDGE (3G)	UMTS (3G, WCDMA)	CDMA (2G)
Noise Calculation	GSM(850/900MHz)	DCS/PCS(1.8/1.9GHz)	DCS/PCS(1.8/1.9GHz)	CDMA(925MHz)
Thermal noise	-173.8dBm	-173.8dBm	-173.8dBm	-173.8dBm
Channel BW	53.0dB	53.0dB	67.0dB	61.0dB
Thermal noise @ BW	-120.8dBm	-120.8dBm	-106.8dBm	-112.8dBm
Noise Figure	6.5dB	7.0dB	8.5dB	7.0dB
Margin	0.0dB	0.0dB	0.0dB	0.0dB
De-sensitization	10.0dB	10.0dB	10.0dB	10.0dB
Allowable Interference Level (dBm)	-124.3dBm	-123.8dBm	-108.3dBm	-115.8dBm

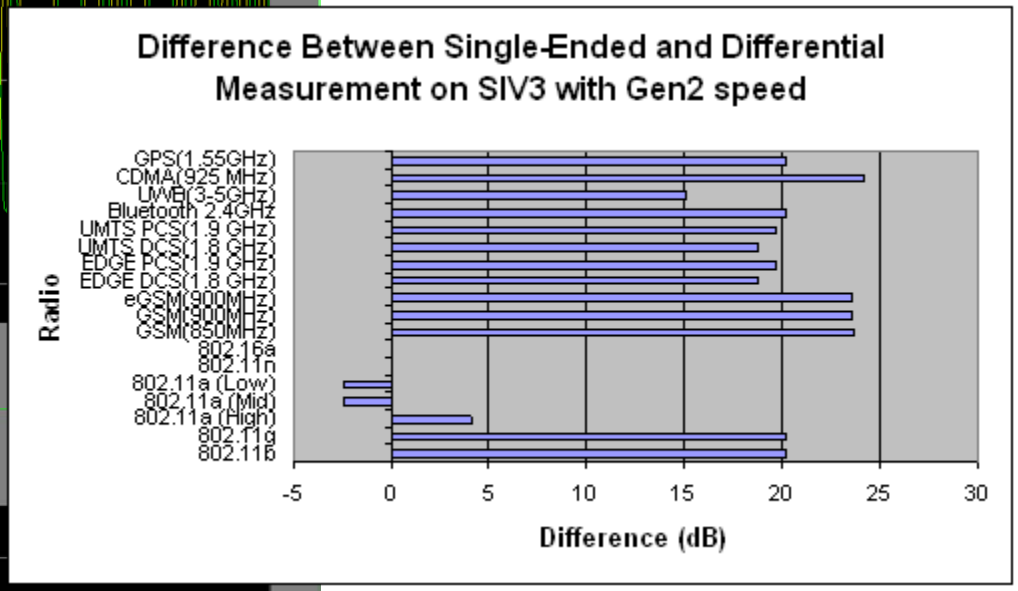
Allowable interference levels in wireless bands

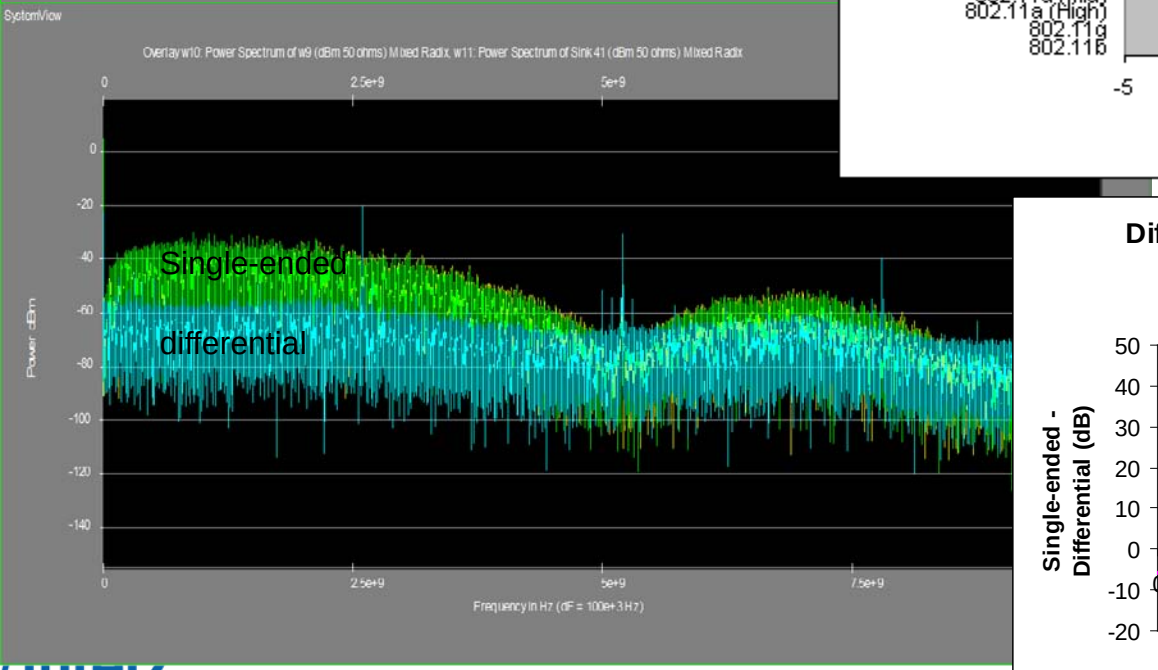
Platform interference levels

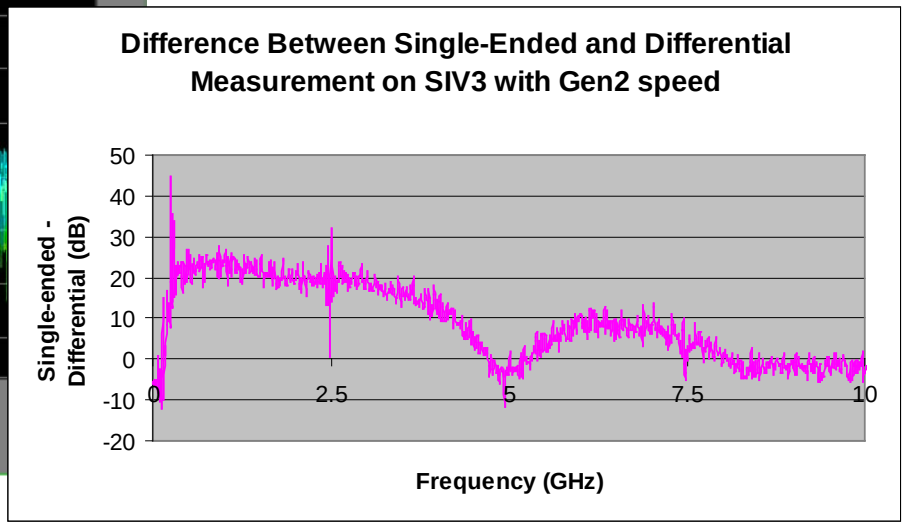
Radio Type	Center Frequency	Device 1 (dBm)	Device 2 (dBm)
802.11b	2.45GHz	-65	-70
802.11g	2.45GHz	-65	-70
802.11a(High)	5.8GHz	-69	-63
802.11a(Mid)	5.3GHz	-77	-76
802.11a(Low)	5.2GHz	-67	-78
Bluetooth(2.4GHz)	2.45GHz	-65	-70
UWB(3-5GHz)	4GHz	-63	-54
GPS(1.575GHz)	1.575GHz	-58	-36
GSM(850MHz)	880MHz	-43	-41
GSM(900MHz)	942MHz	-41	-42
EDGE(1.8GHz)	1842MHz	-41	-39
EDGE(1.9GHz)	1960MHz	-68	-63
UMTS(1.8GHz)	1842MHz	-41	-39
UMTS(1.9GHz)	1960MHz	-68	-63



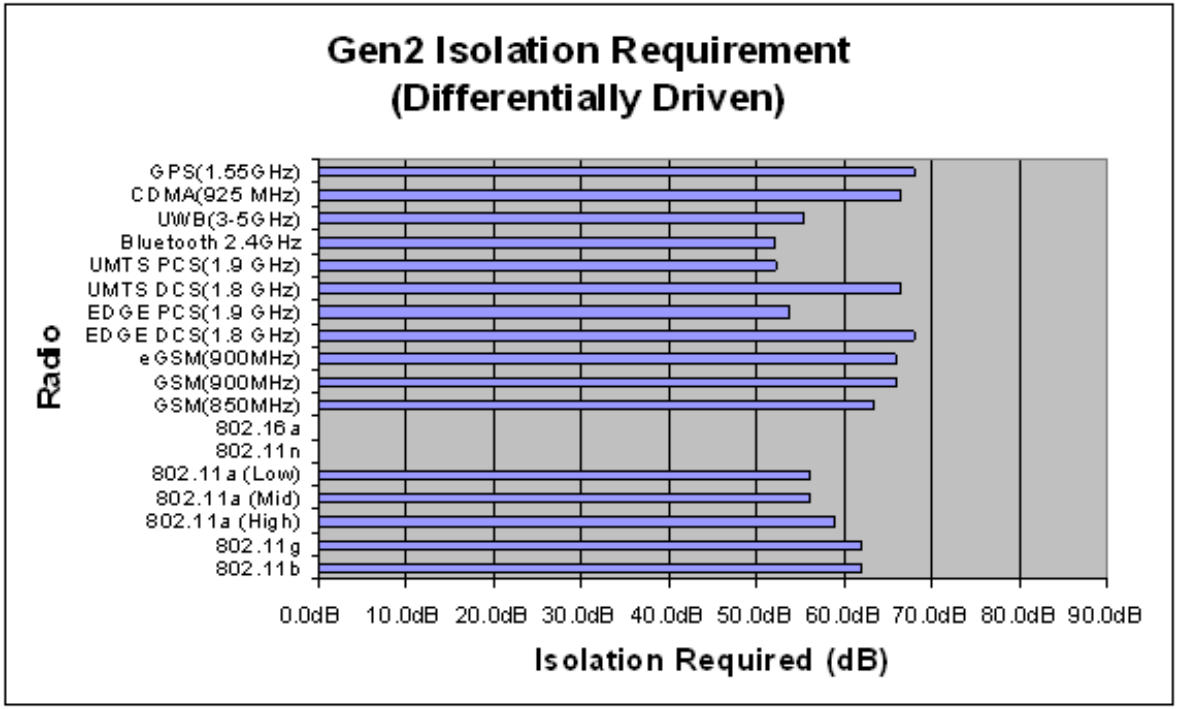
Note that differential signals can increase the noise level over single-ended in the spectral nulls

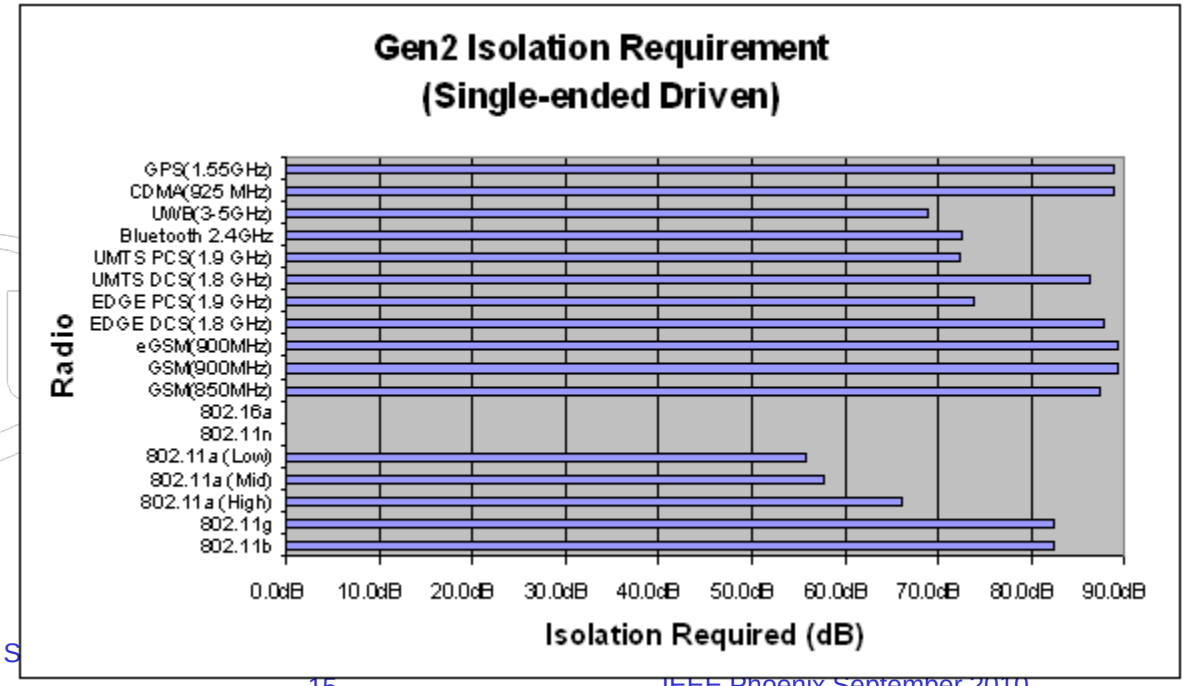


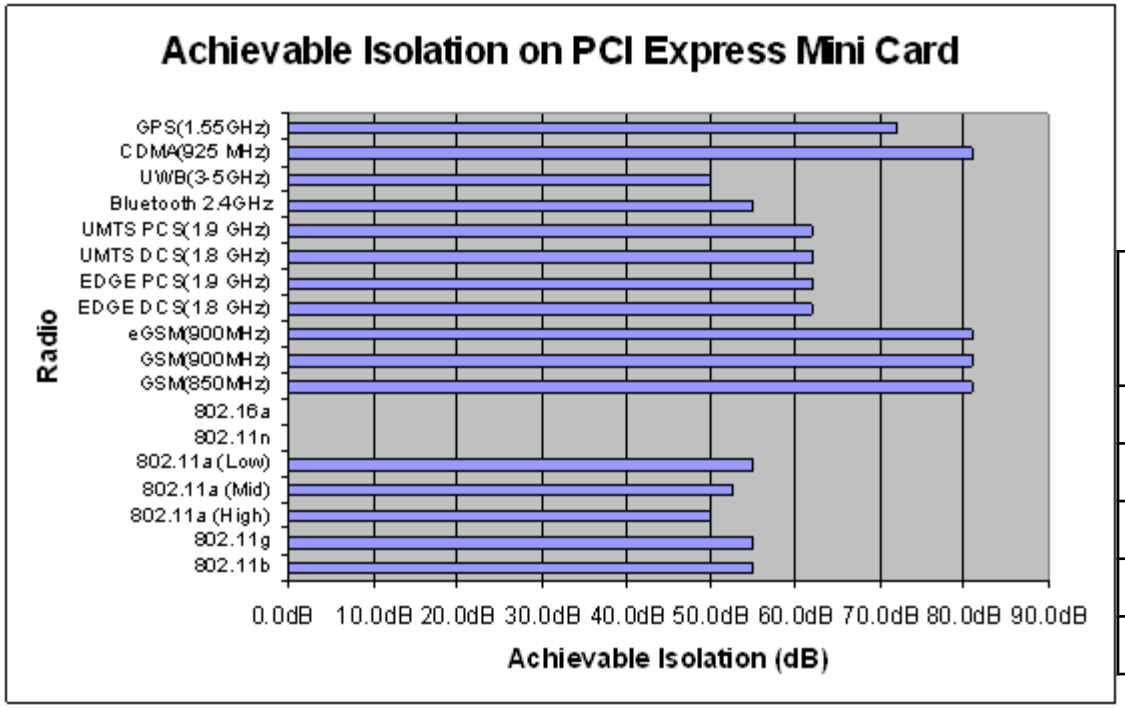




Working from the Radio specs we can Generate a graph of Required platform Isolation levels to Guarantee radio performance

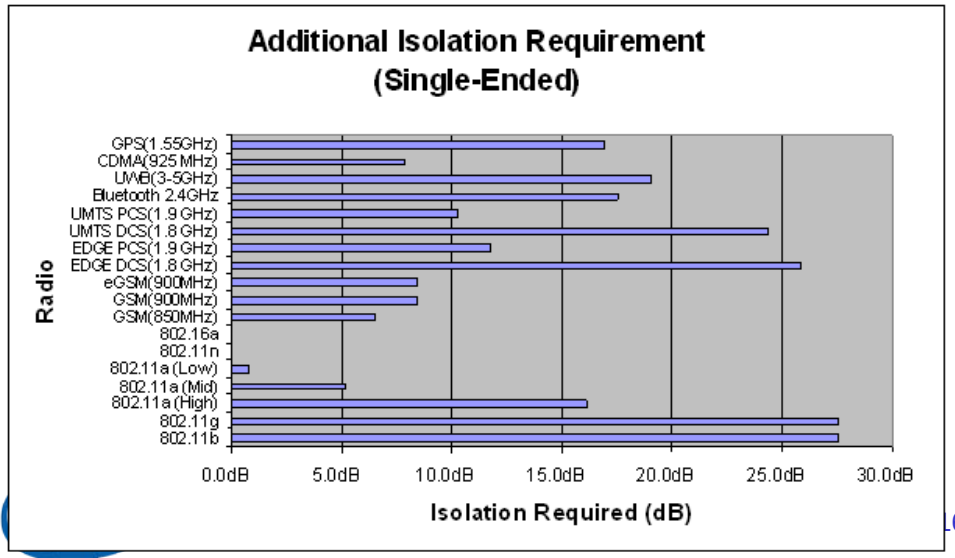


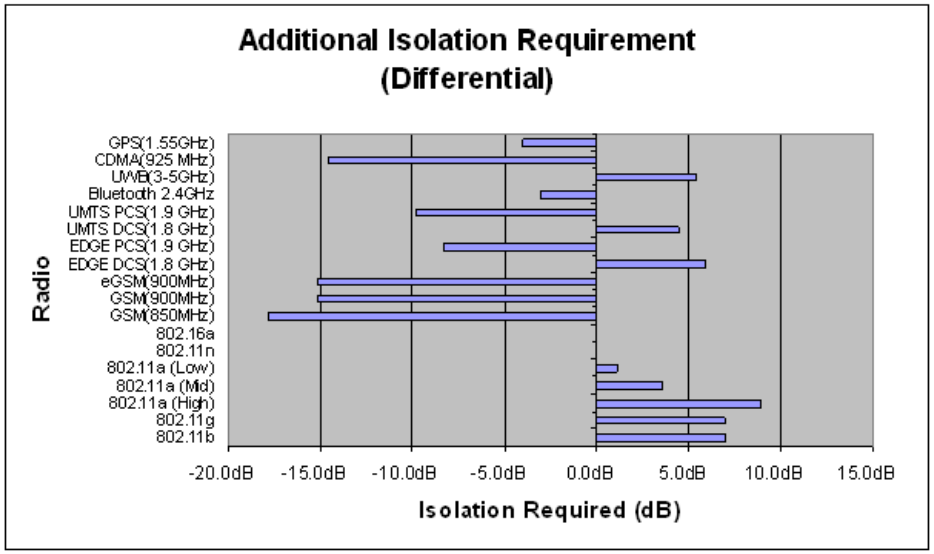




Interference Level	Operating Range Reduction for Constant Throughput
0dB	0%
3dB	19%
5dB	30%
10dB	50%
20dB	75%

Using Best design practices …we still need more!





Wireless and EMI: Challenges

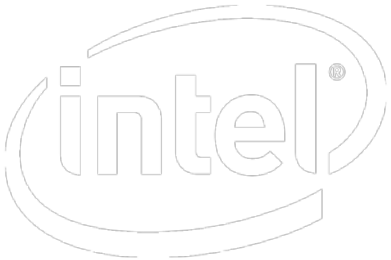
- No longer limited to a regulation issue
  - Wireless performance will drive EMI requirements
- Reducing EMI everywhere not realistic
  - Lowering limits by 30+dB not an option
- Wireless proliferation accelerating
  - Multiple wireless sub systems on the platform
  - 7+ wireless antennas on a single platform
- Separation / isolation of EMI sources and wireless (antennas and components)
  - System form factors trending smaller

EMI/EMC strategy for Wireless

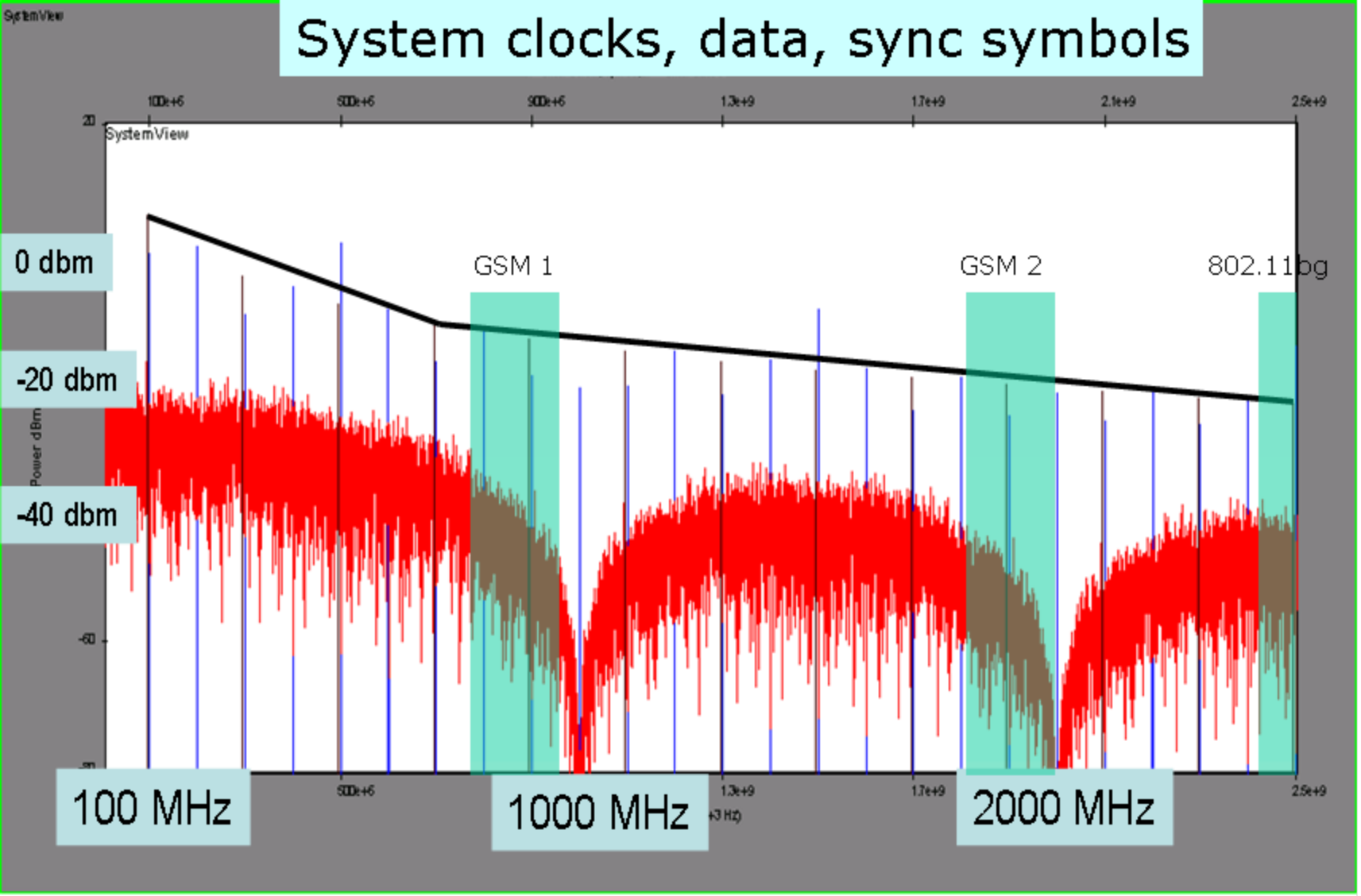
- Starting point is best possible system EMI design
  - Focus of today's workshop
  - "Platform EMC for wireless"
- Selectively reduce emissions where it matters
  - Only in wireless bands
  - Only in wireless bands "in use"
- Trade off performance between wireless and non-wireless bands
  - Deliberately "squash" the EMI balloon where needed
  - Reduce the emissions at frequencies of interest knowing that emissions at other frequencies may increase
  - Must still meet EMI regulations

Some preliminaries in spectral analysis

We'll begin by examining the structure of the signals that ICs generate. Primarily, we will look at clocks, data, and symbol structures such as those that generate displays. All of these signals are present in the ICs, understanding their spectral content can give us insight into how they can couple to incidental antennas such as heat sinks, power planes.



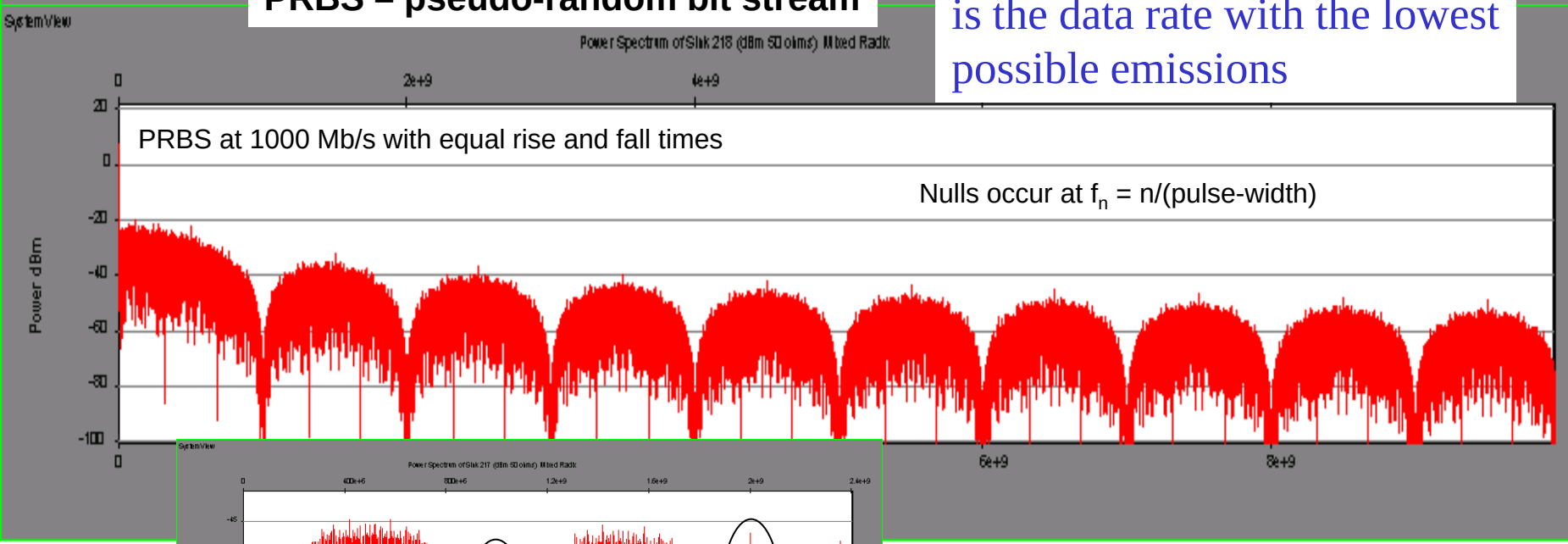
System clocks, data, sync symbols



system signals produce noise in wireless bands and degrade performance

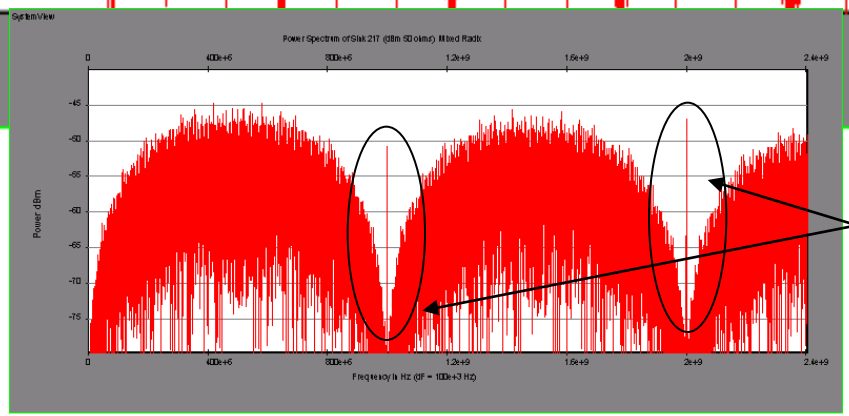
PRBS – pseudo-random bit stream

Given a bit size, the PRBS is the data rate with the lowest possible emissions

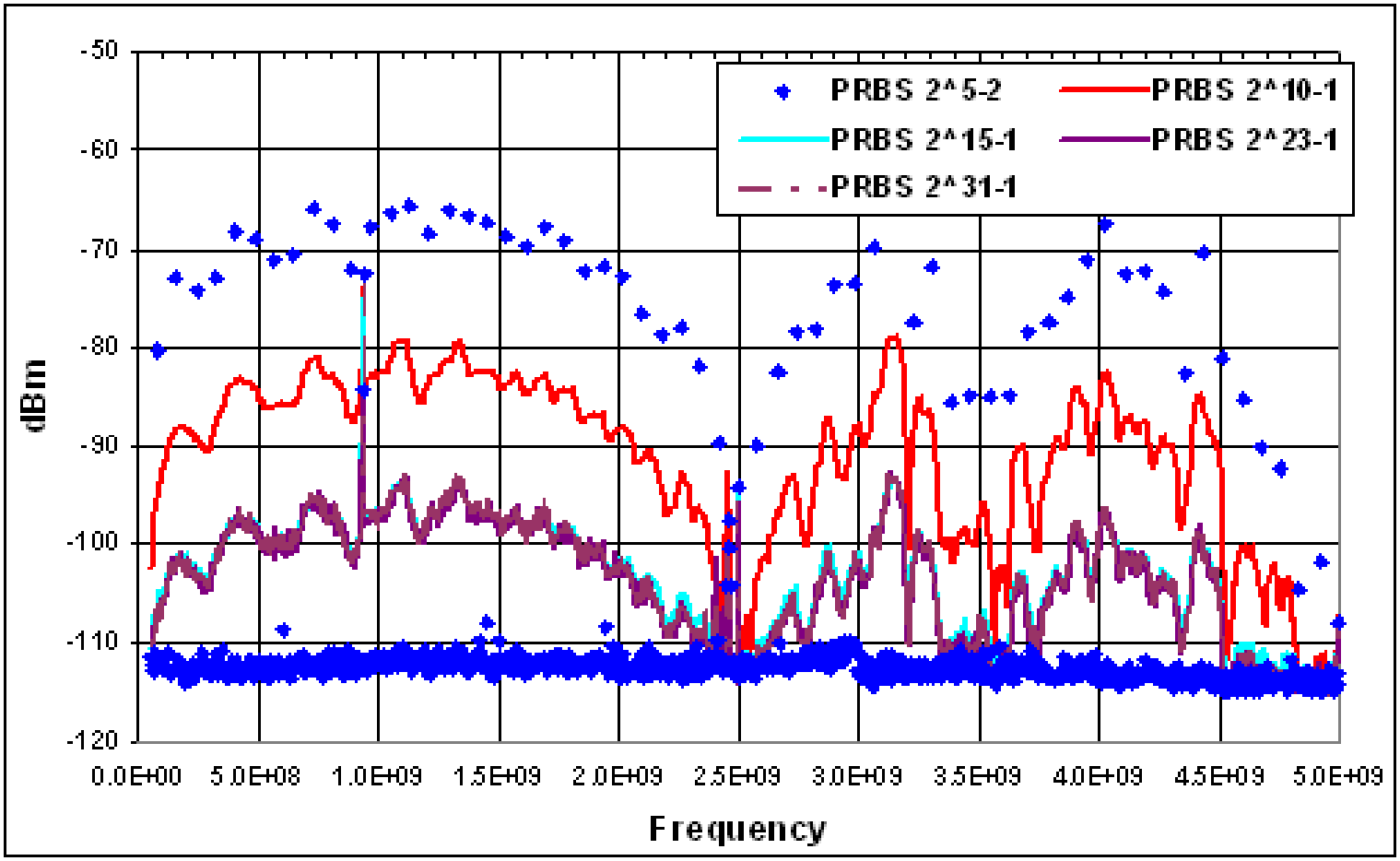


PRBS at 1000 Mb/s with equal rise and fall times

Nulls occur at f_n = n/(pulse-width)



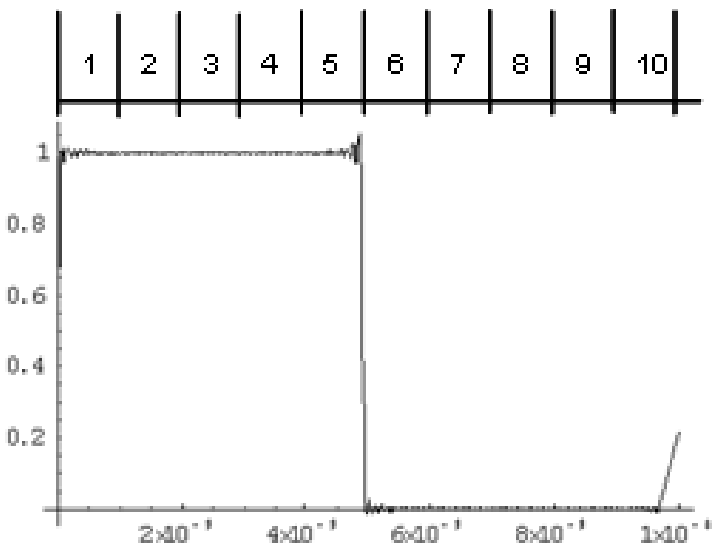
Note the change when the rise and fall times are not equal !
We see a harmonic spike at the data rate.
This spike would also appear if the unit interval (bit width) were to be varying, jittering.



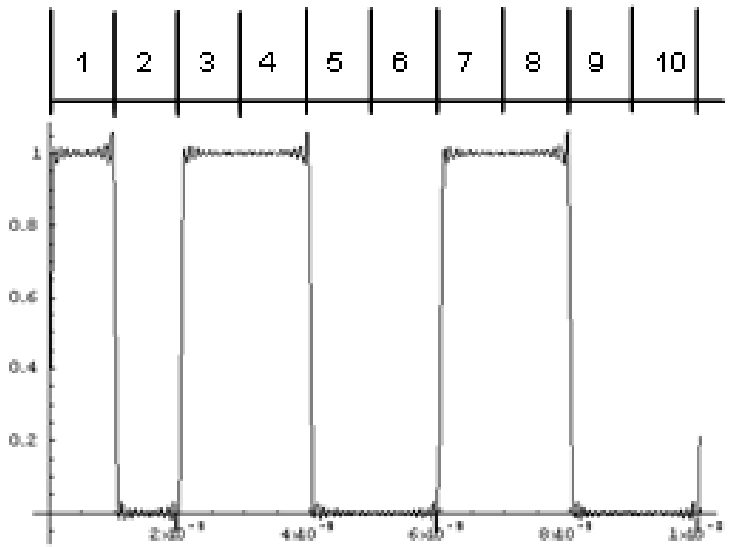
8
512
16384
$4.19\ 10^6$
$1\ 10^9$

GTEM Measurements of PRBS signals with varying sizes of symbol sets showing how distribution of energy into larger symbol set sizes reduces the peak envelope of emissions while increasing the spectral density

Symbols occupy a space between clocks and random data sequences. They are typically used as identifiers for sync operations.



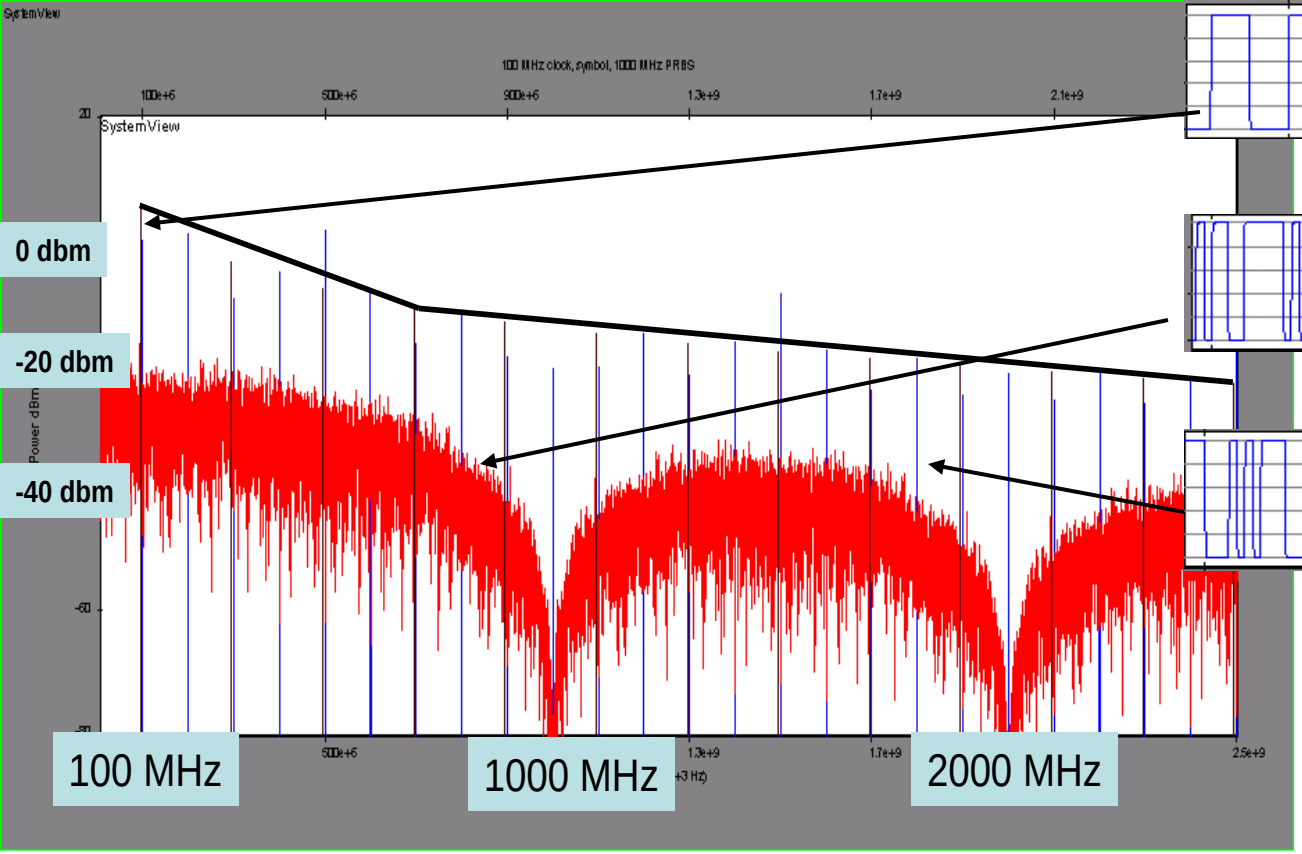
Clock as symbol

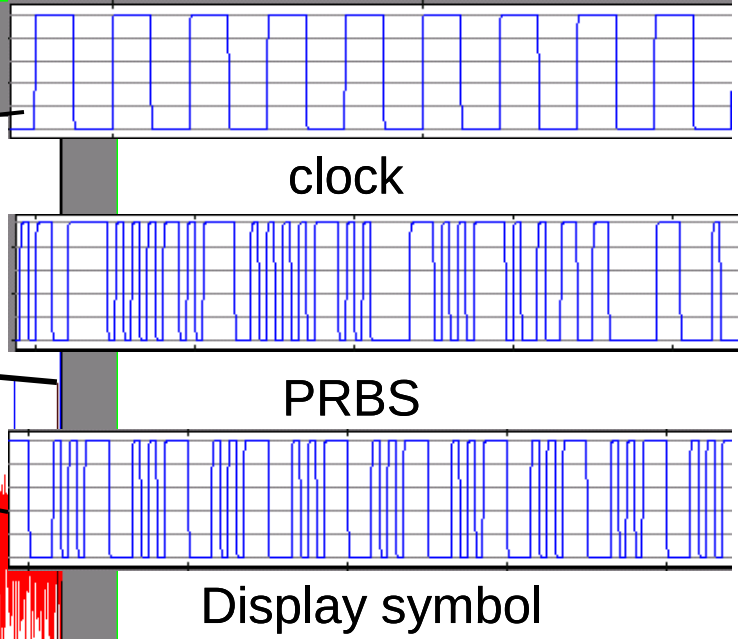


10 bit display control symbol

A symbol is a complex bit sequence usually employed in display systems for sync functions.

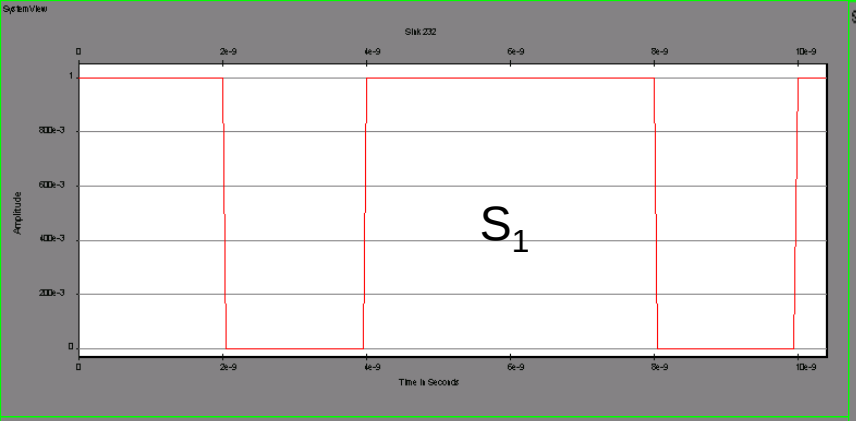
We will show a method whereby a given symbol set can be well ordered with regard to their radiated emissions impact.
By ordering the symbol set we then can determine the effect of any given symbol in relation to the rest of the symbols in the set.
The method can be extended to analyze the impact of sequences of symbols.

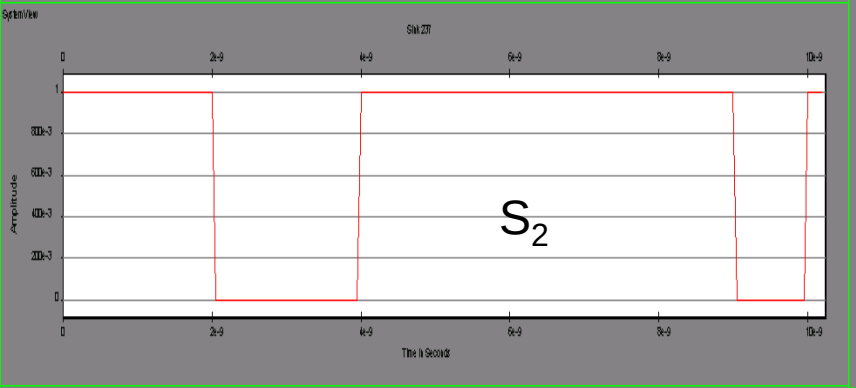


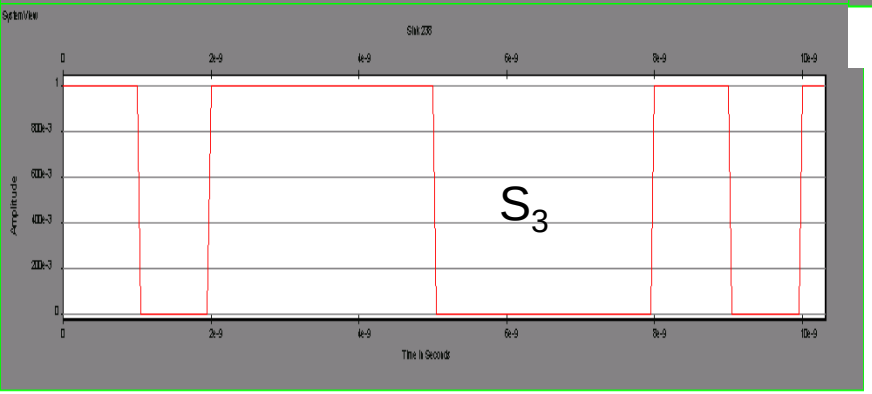


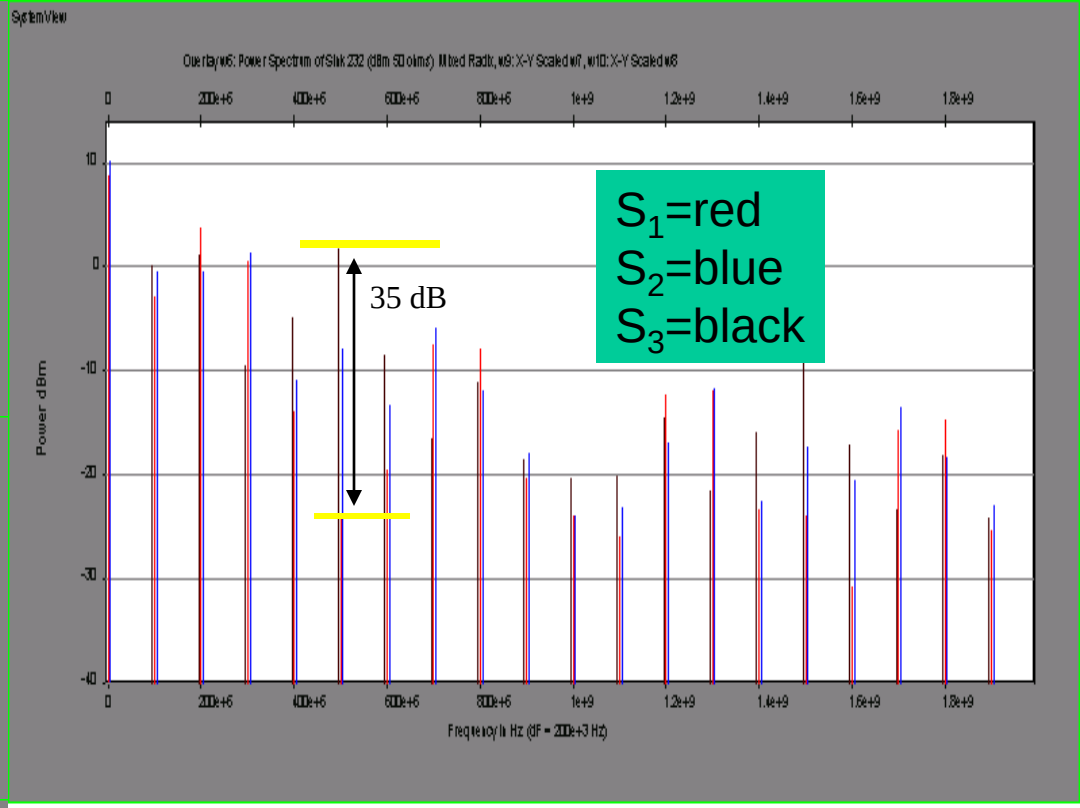
The clock is seen to have no even harmonics and the symbol is seen to have both even and odd harmonics, all at the fundamental clock spacing of 100 MHz. The clock fundamental is seen to have the highest peak of the spectrum set, the PRBS has the lowest peak set and the symbol is seen to have some spectral components that fall above local clock spectral peaks.

Comparing the signal types
~30 dB variation!







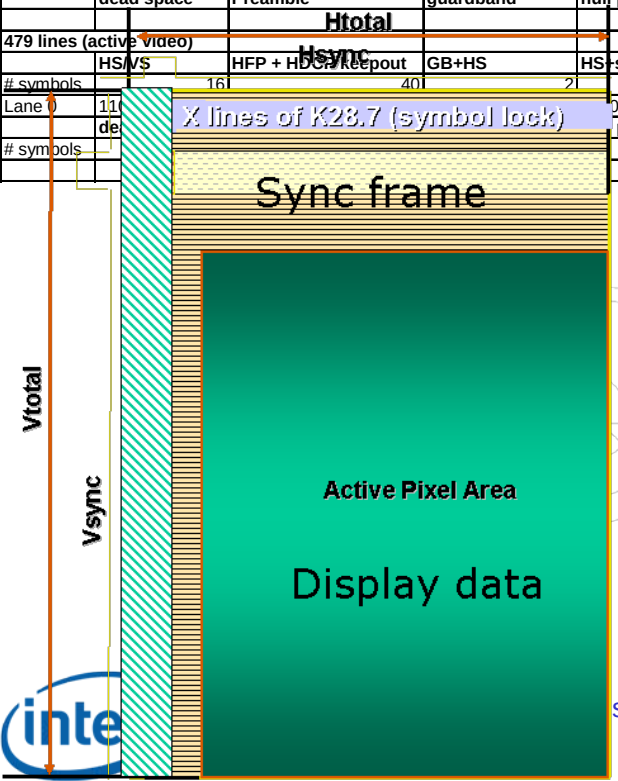


We look at signals with complex time structure: display symbols

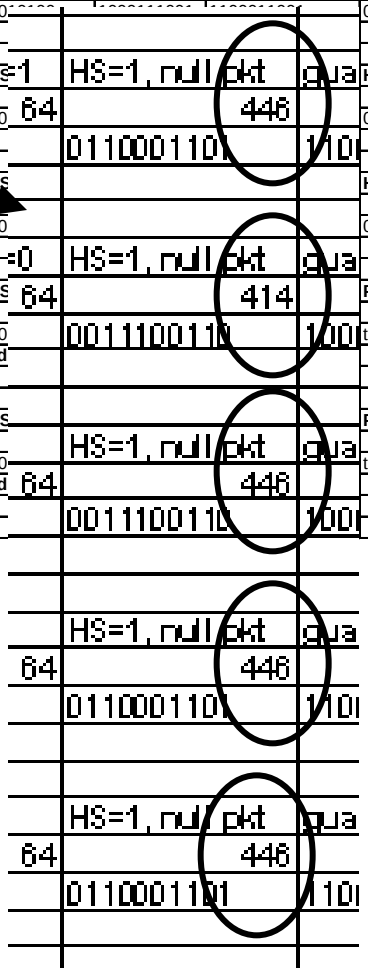
Different symbols have distinctly different spectra

Looking at the spectra of 10 bit symbols

Lane 0													
10 lines (vertical front porch)													
	HS/VS	**GB**	**spec start of null**	**rest of HS=1**	**HS=0 and VS=1**	**HS=1, null pkt**	**guardband**	**HS/VS**	**GB**	**spec start of null**	**HS=1, null pkt**	**GB**	
# symbols	12	2	1	1	64	446	2	12	2	1	255	2	
Lane 0	1101010101	1100001101	0011110010	0110001101	0011100110	0110001101	1100001101	1101010101	1100001101	0011110010	0110001101	1100001101	
1 line (start of VS, includes HDCP vertical keepout)													
	HS/VS	**GB**	**spec start of null**	**rest of HS=1**	**HS=0 and VS=0**	**HS=1, null pkt**	**guardband**	**HDCP Keepout**	**GB**	**spec start of null**	**HS=1, null pkt**	**GB**	**HS/VS**
# symbols	12	2	1	1	64	414	2	162	2	1	127	2	10
Lane 0	1101010101	1100001101	0011110010	0110001101	0011001101	0011100110	1000111001	1101010100	1000111001	1100011001	1001110010	1000111001	1101010100
1 line (bulk of VS)													
	HS/VS	**GB**	**spec start of null**	**rest of HS=1**	**HS=0**	**HS=1, null pkt**	**guardband**	**HS/VS**	**GB**	**spec start of null**	**HS=1, null pkt**	**GB**	
# symbols	12	2	1	1	64	446	2	12	2	1	255	2	
Lane 0	1101010100	1000111001	1100011001	1001110010	0011001101	0011100110	1000111001	1101010101			0011100110	1000111001	
1 line (end of VS, starts back porch)													
	HS/VS	**GB**	**spec start of null**	**rest of HS=1**	**HS=0**	**HS=1, null pkt**	**guardband**	**HS/VS**			**HS=1, null pkt**	**GB**	
# symbols	12	2	1	1	64	446	2				255	2	
Lane 0	1101010100	1000111001	1100011001	1001110010	0011100110	0110001101	1100001101	11010			0110001101	1100001101	
32 lines (vertical back porch without active pixels)													
	HS/VS	**GB**	**spec start of null**	**rest of HS=1**	**HS=0**	**HS=1, null pkt**	**guardband**	**HS/VS**			**HS=1, null pkt**	**GB**	
# symbols	12	2	1	1	64	446	2				255	2	
Lane 0	1101010101	1100001101	0011110010	0110001101	0011100110	0110001101	1100001101	11010			0110001101	1100001101	
1 line (end of vertical blank, start of active)													
	HS/VS	**GB**	**spec start of null**	**rest of HS=1**	**HS=0**	**HS=1, null pkt**	**guardband**	**HS/VS**			**Pixel data**		
# symbols	12	2	1	1	64	62	2				640		
Lane 0	1101010101	1100001101	0011110010	0110001101	0011100110	0110001101	1100001101	11010			tbd from list		
	dead space	**Preamble**	**guardband**	**null pkt**	**guardband**	**dead space**	**preamble**	**guard**					
479 lines (active video)													
	HS/VS	**HFP + HDCP keepout**	**GB+HS**	**HS+spec start of null**	**HS=0 + null**	**HS=1, null pkt**	**guardband**	**HS/VS**			**Pixel data**		
# symbols	16	40	2	1	21	42	2				640		
Lane 0	110			0011001	0011100110	0110001101	1100001101	11010			tbd from list		
	de			pkt	guardband	dead space	preamble	guard					
# symbols				64	2	26	8						



Note the dominance of a reduced set of the symbols



A portion of the repeated frame lines

A typical display frame header

A review of display frames:

Single symbol display frames: s_4 from the list below

Multi-symbol display frames: s_1, s_4, s_5 used for 3 symbol frame

symbol list of frame (red are dominant):

s_1: 1101010101

s_2: 1100001101

s_3: 0011110010

s_4: 0110001101

s_5: 0011100110

s_6: 0011001101

s_7: 1000111001

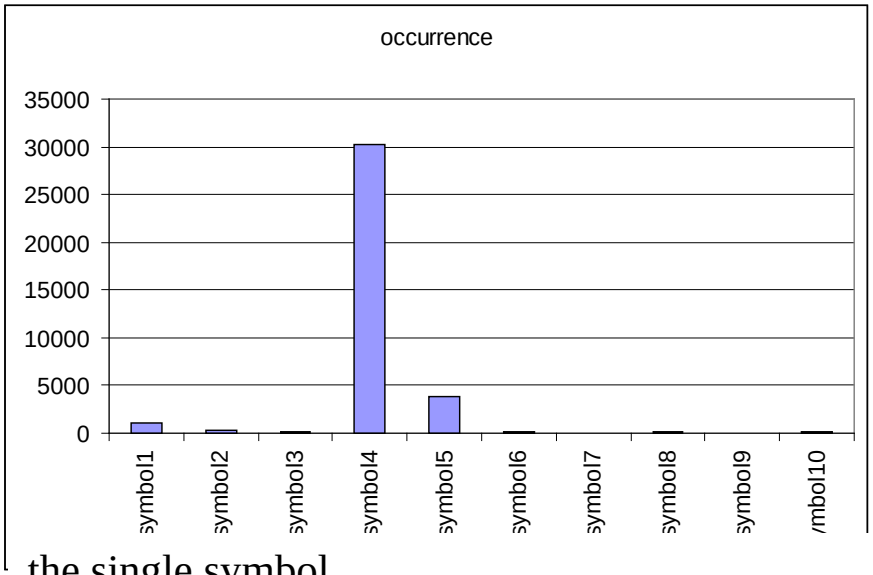
s_8: 1101010100

s_9: 1100011001

s_{10}: 1001110010

These 10 symbols comprise the symbol set for a specific display frame format.

3 symbols in this frame dominate the symbol distribution.



the single symbol

contains 84% of the energy

3 symbols make up 97% of the energy

PRBS: pseudo-random bit streams; similar to pixel data)

Analysis of Display Frame Symbols

An example of the Fourier series components for a given symbol:

$$\begin{bmatrix} 0.094442 & 0.0274379 & 0.078934 & 0.050093 & 0.0566826 & 0.0642938 & 0.0321394 & 0.0682996 \\ 0.00991802 & 0.0626199 & 0.00628632 & 0.0497614 & 0.0144929 & 0.0334912 & 0.0147511 & 0.0178311 \\ 0.0089194 & 0.00606162 & 2.97922\cdot 10^{-16} & 2.52088\cdot 10^{-16} & 0.00876086 & 0.000275321 & 0.0147465 & 0.00378625 \\ 0.0165805 & 0.00980565 & 0.0143297 & 0.0152596 & 0.00928135 & 0.0182157 & 0.00339796 & 0.0178127 \\ 0.00135876 & 0.0143741 & 0.00362571 & 0.0091575 & 0.00298793 & 0.00385202 & 7.44804\cdot 10^{-17} & 7.61173\cdot 10^{-17} \end{bmatrix}$$

This can be viewed as a vector in C^n space where n is the number of harmonic components.
The inner product is then:

$$\left\|(v_1, v_2, v_3 \ldots v_n)\right\| = \left|\sqrt{(v_1, v_2, v_3 \ldots v_n) \bullet (v_1, v_2, v_3 \ldots v_n)}\right|$$

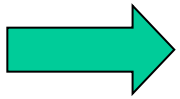
$$where \quad v_1 = (-.094442 - j.02743),\ v_2 = (-.0789 - j.050)$$

$$etc$$

The inner product is chosen because it is conceptually easy to appreciate, and it is an invariant “length” of any given vector. It is also a real number and therefore the set of inner products for the set of symbols can then be ordered.

comparing the spectral impact
Of display symbols

D3	D2	D1	D0	q_out[9:0]
0	0	0	0	0b10 1001 1100
0	0	0	1	0b10 0110 0011
0	0	1	0	0b10 1110 0100
0	0	1	1	0b10 1110 0010
0	1	0	0	0b01 0111 0001
0	1	0	1	0b01 0001 1110
0	1	1	0	0b01 1000 1110
0	1	1	1	0b01 0011 1100
1	0	0	0	0b10 1100 1100
1	0	0	1	0b01 0011 1001
1	0	1	0	0b011001 1100
1	0	1	1	0b10 1100 0110
1	1	0	0	0b10 1000 1110
1	1	0	1	0b10 0111 0001
1	1	1	0	0b01 0110 0011
1	1	1	1	0b10 1100 0011



Symbol inner-product

	symbol
clock	0.496
t1011100010	0.49
t0110001110	0.418
t1001110001	0.418
t1011001100	0.383
t1001100011	0.376
t0110011100	0.376
t0100111001	0.347
t1011000110	0.347
t0101110001	0.307
t1010001110	0.307
80percent	0.303
t1011100100	0.269
t0100111100	0.24
t1011000011	0.24
t100011110	0.237
t1010011100	0.225
t0101100011	0.225
single bit	0.2

The clock shows up as
The worst symbol

Performing the analysis on the symbol set and ordering the set according to the IP

Very pretty…but how does it agree with real measurements of the symbols?
A little later on, we will show measurements of symbol impact on wireless performance

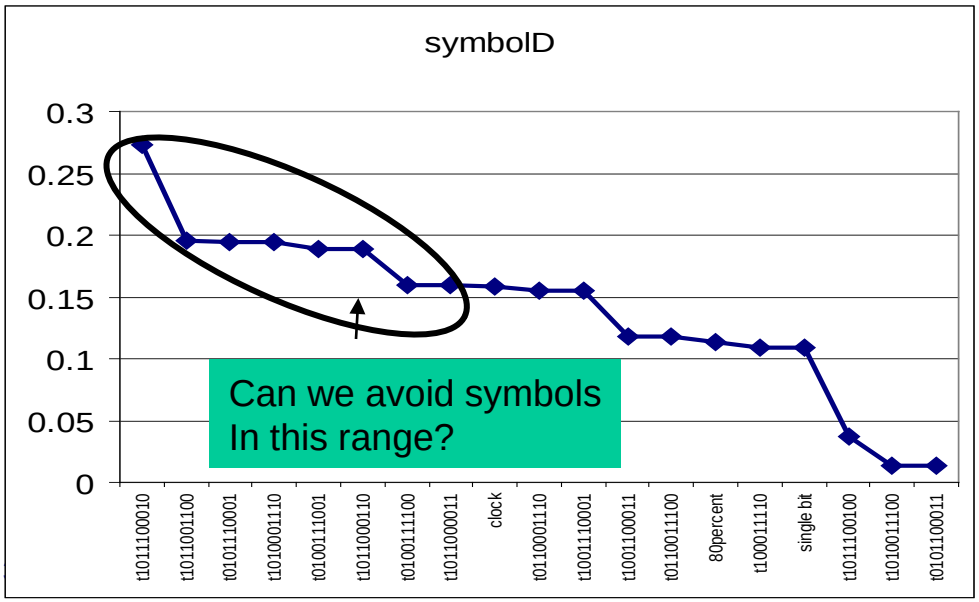
D3	D2	D1	D0	q_out[9:0]
0	0	0	0	0b10 1001 1100
0	0	0	1	0b10 0110 0011
0	0	1	0	0b10 1110 0100
0	0	1	1	0b10 1110 0010
0	1	0	0	0b01 0111 0001
0	1	0	1	0b01 0001 1110
0	1	1	0	0b01 1000 1110
0	1	1	1	0b01 0011 1100
1	0	0	0	0b10 1100 1100
1	0	0	1	0b01 0011 1001
1	0	1	0	0b011001 1100
1	0	1	1	0b10 1100 0110
1	1	0	0	0b10 1000 1110
1	1	0	1	0b10 0111 0001
1	1	1	0	0b01 0110 0011
1	1	1	1	0b10 1100 0011

Symbol inner-product

	symbolD
t1011100010	0.273
t1011001100	0.195
t0101110001	0.194
t1010001110	0.194
t0100111001	0.189
t1011000110	0.189
t0100111100	0.159
t1011000011	0.159
clock	0.158
t0110001110	0.155
t1001110001	0.155
t1001100011	0.118
t0110011100	0.118
80percent	0.113
t100011110	0.109
single bit	0.109
t1011100100	0.037
t1010011100	0.013
t0101100011	0.013

Normalized comparison

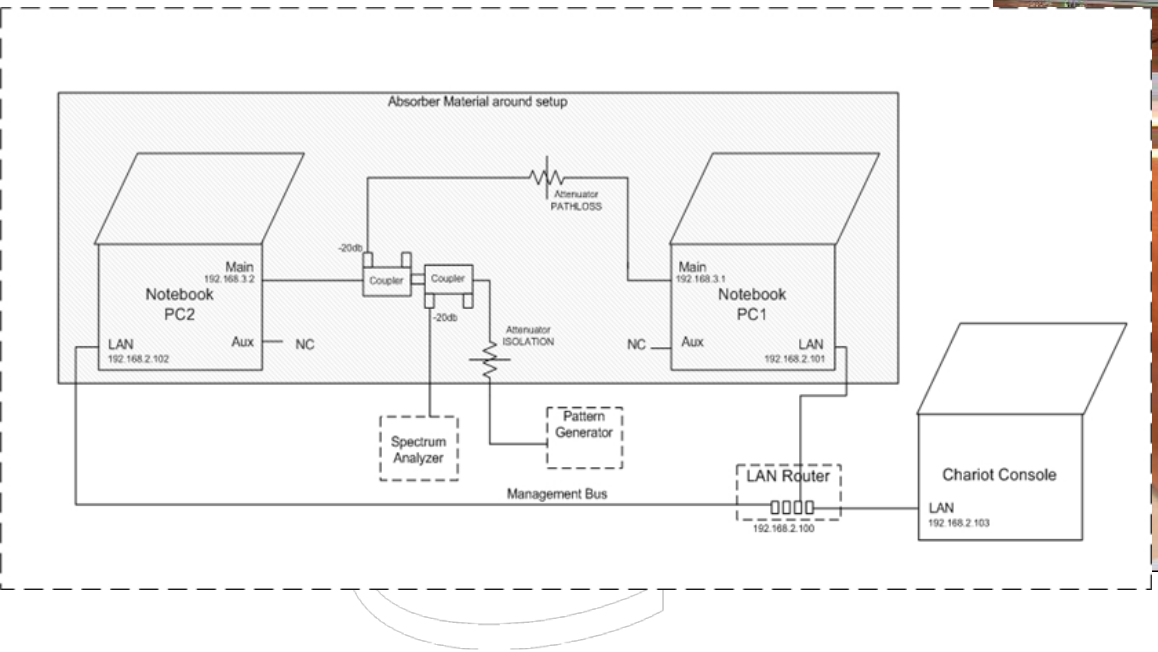
	symbolD	dB margin gain
t1011100010	0.273	0
t1011001100	0.195	2.922560714
t0101110001	0.194	2.967218342
t1010001110	0.194	2.967218342
t0100111001	0.189	3.194016857
t1011000110	0.189	3.194016857
t0100111100	0.159	4.695310454
t1011000011	0.159	4.695310454
clock	0.158	4.750111202
t0110001110	0.155	4.916618977
t1001110001	0.155	4.916618977
t1001100011	0.118	7.285612795
t0110011100	0.118	7.285612795
80percent	0.113	7.661684071
t100011110	0.109	7.974722982
single bit	0.109	7.974722982
t1011100100	0.037	17.35921846
t1010011100	0.013	26.44438589
t0101100011	0.013	26.44438589

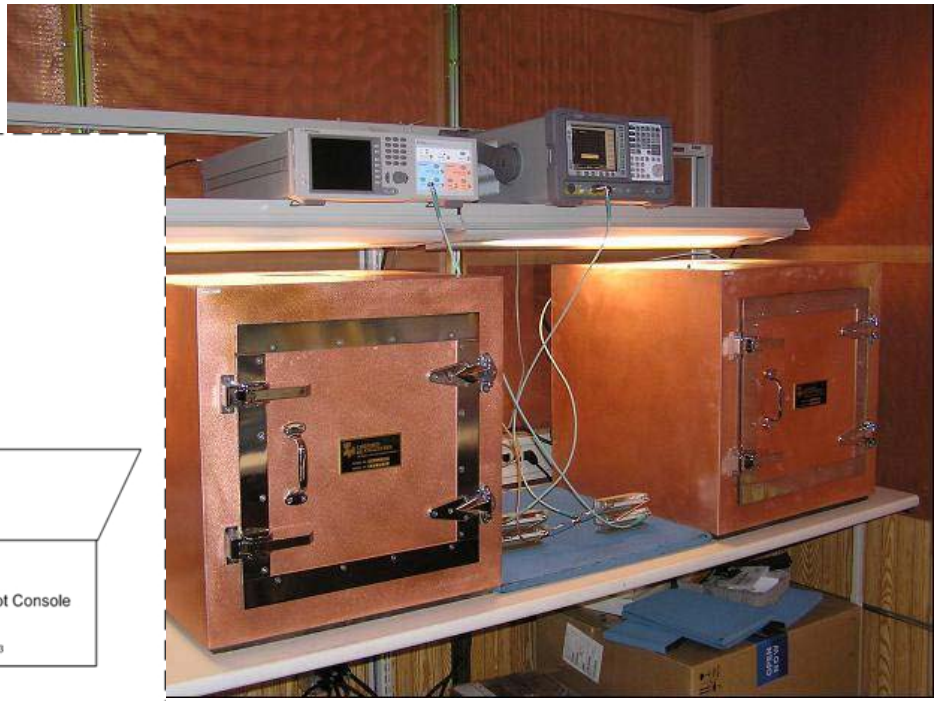


comparing the spectral impact of differentiated display symbols symbols

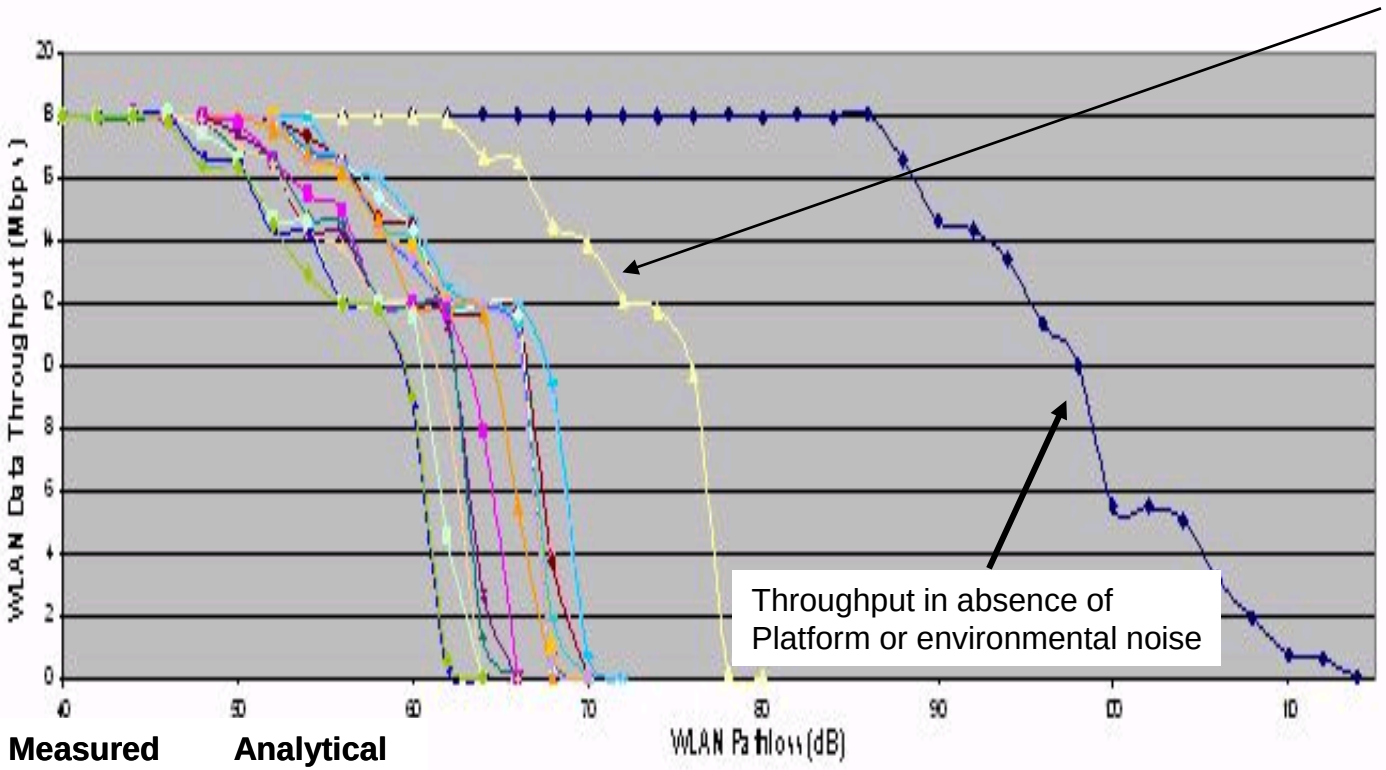
Patent pending

Each laptop is isolated from each other by being placed in a desktop RF isolation chamber. The system is completely isolated from the laboratory environment.
The pattern generator output Is fed to a directional coupler which is in line with the Communication link between the isolation chambers.
Chariot software is used to measure throughput





Throughput impact of display symbols to wireless performance



Least impact

greatest impact

Measured ranking

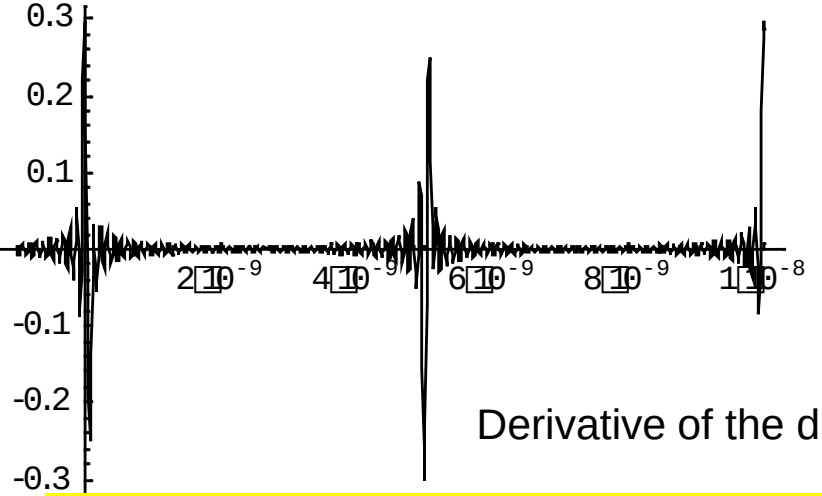
Analytical ranking

Ranking the impact of the TERC4 symbols on wireless performance

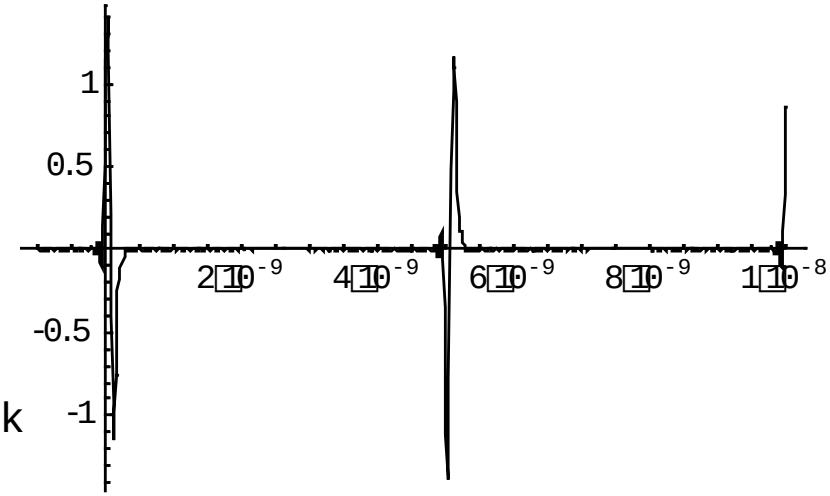
The analysis indicates a single symbol having lesser impact and clearly separated from the rest of the symbol set. The measured results show the same. The analysis indicates a spread of 14 dB between the least and greatest symbol and the measured shows the same. So, it is clear that the method of inner product ranking has merit and can be correlated with measurement of real performance impact.

The differentiated symbol ranking matches the measured impact ranking

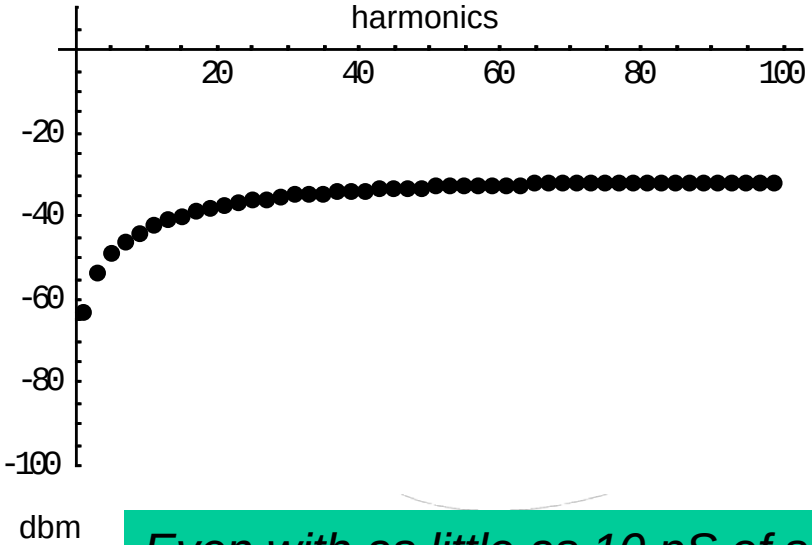
Analysis for differential Signals

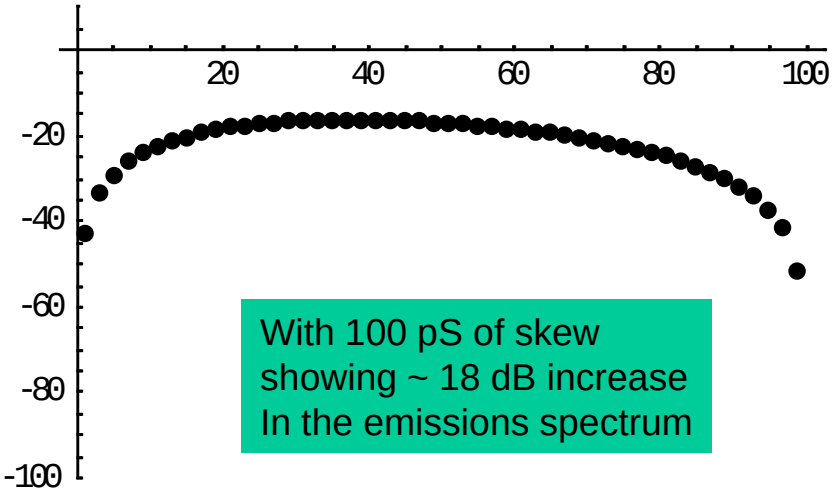


Derivative of the differential clock



With 10 pS of skew between Tx+ and Tx-





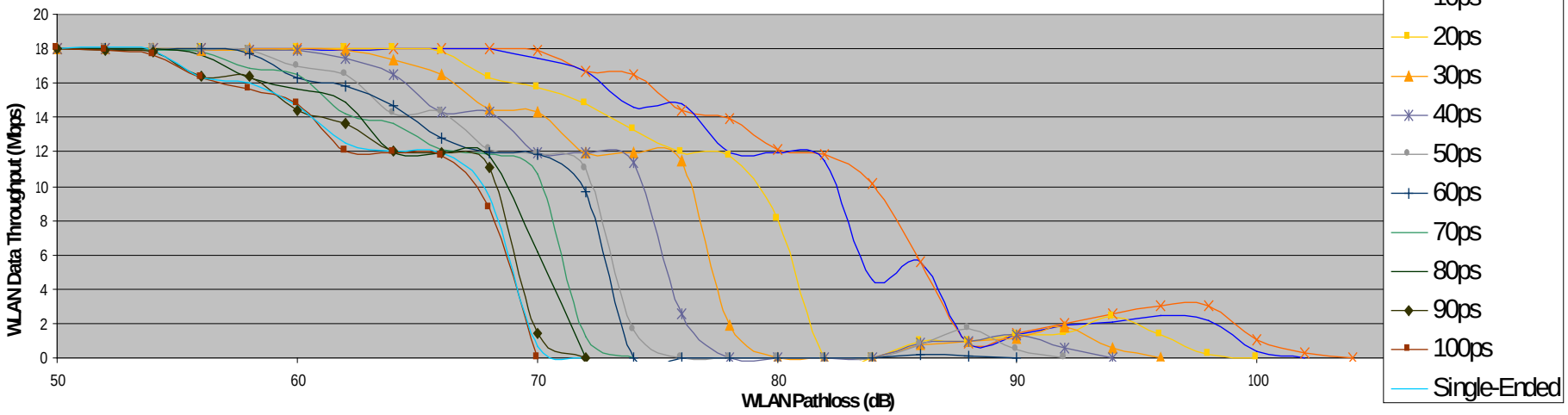
With 100 pS of skew showing ~ 18 dB increase In the emissions spectrum

Even with as little as 10 pS of skew, there remains a significant signal to contribute to radiation

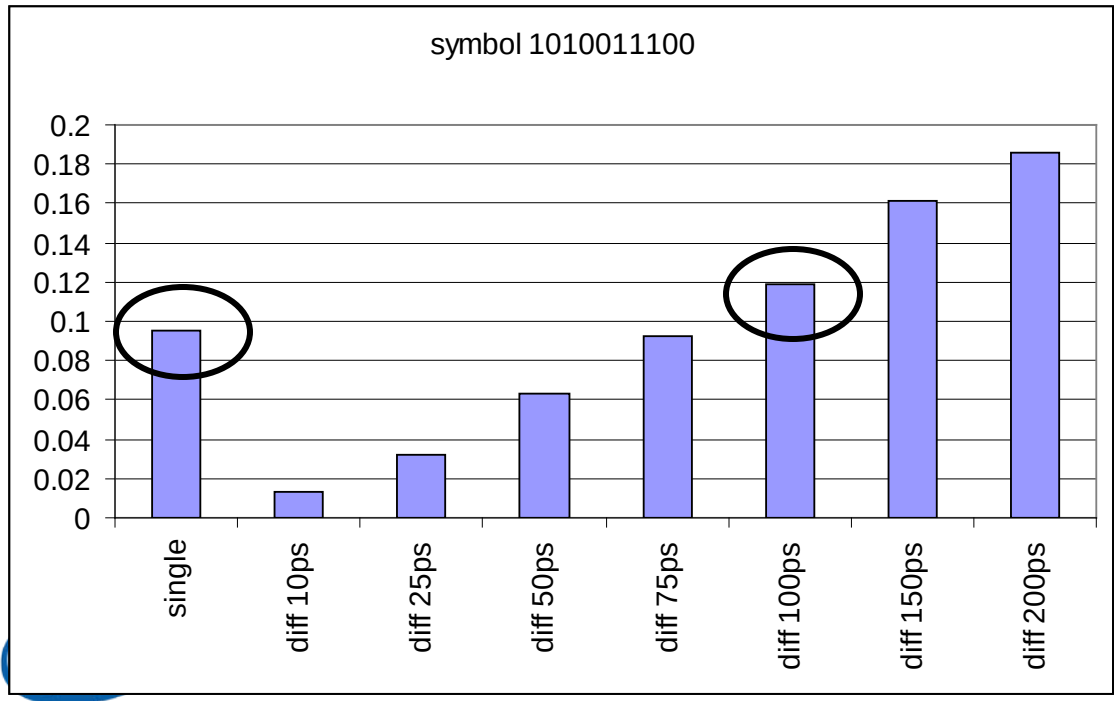
Generating the rank order for differentiated differential signals

	Single	differential
	IPS(n,1,50)	IPD(n,1,50)100ps
1011100010	0.177	0.26
1011001100	0.127	0.189
0101110001	0.126	0.187
1010001110	0.126	0.187
0100111001	0.12	0.174
1011000110	0.12	0.174
0100111100	0.103	0.153
1011000011	0.103	0.153
1111100000	0.101	0.15
0110001110	0.098	0.142
1001110001	0.098	0.142
0110011100	0.081	0.122
1001100011	0.07	0.122
0100011110	0.069	0.099
1011100100	0.042	0.061
1010011100	0.016	0.025
0101100011	0.016	0.025

the differential symbols, while having the same rank order, produce a higher impact when there is significant skew in the Intra-pair skew.



Graph 6



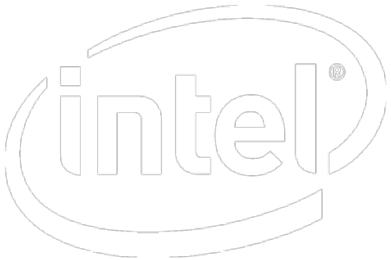
measurement

the effect of varying the skew in the differential symbol, from 10pS to 200pS.

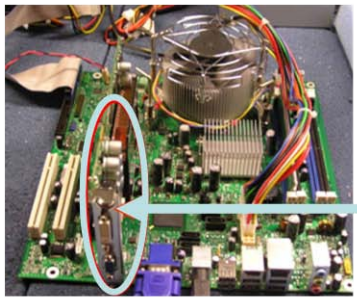
When skew ~ = rise-time, the RFI Impact ~= single ended

Analytical model

Mitigation

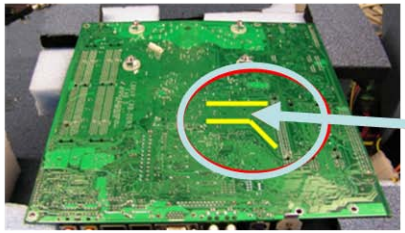


Broad Band Horn Antenna Measurements of uBTX CRB board



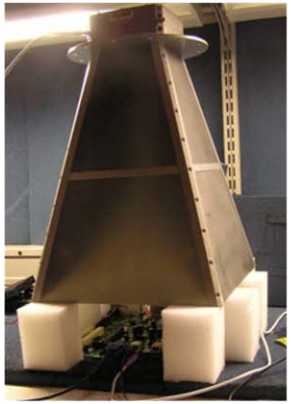
PCI Express Video Card

Front side



PCIe bus traces

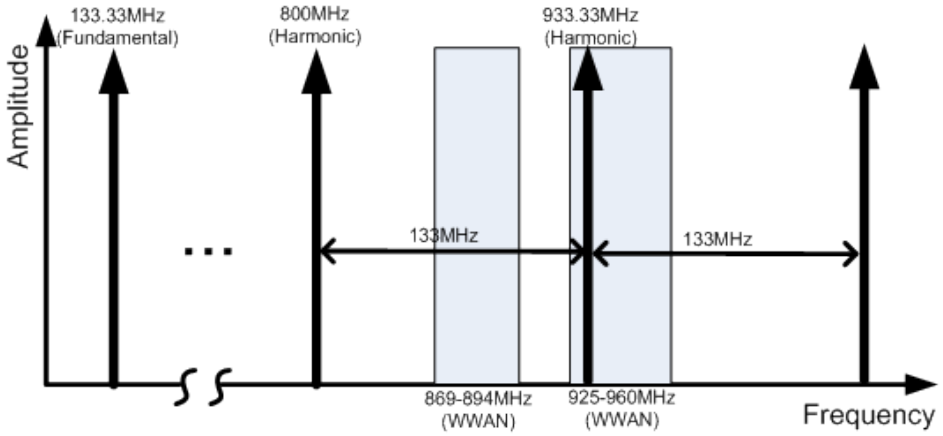
Back side



Horn antenna measurements

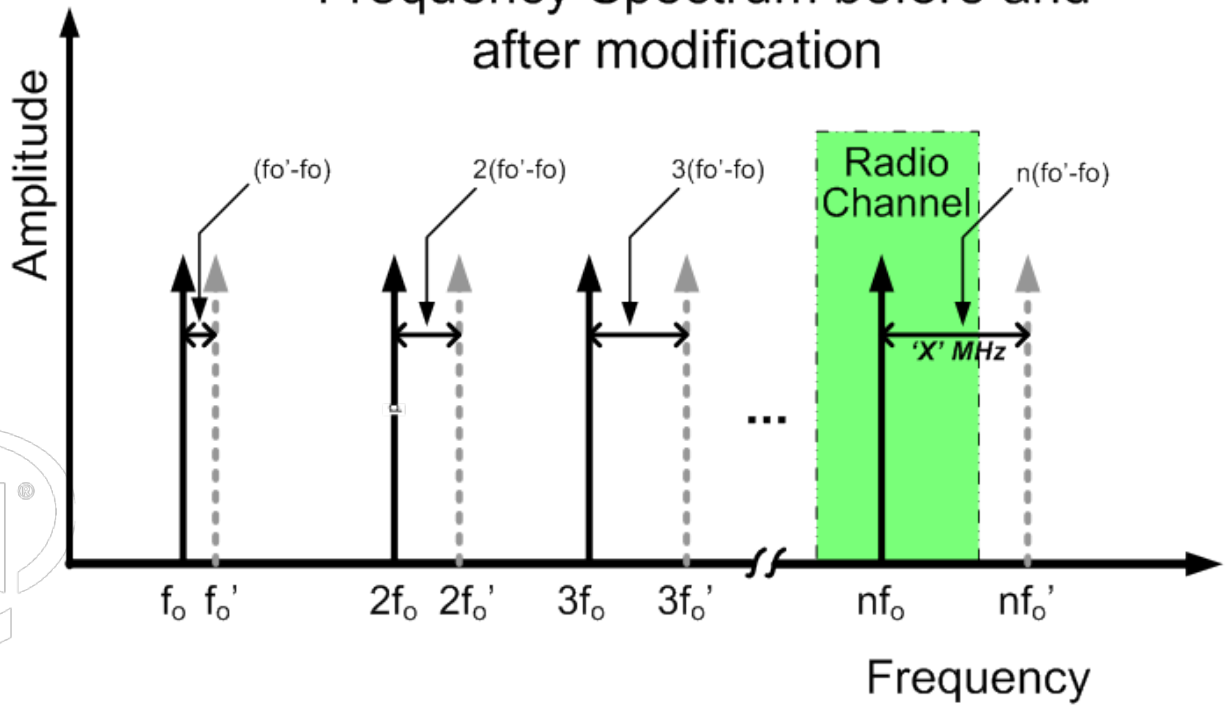
Intel's near field scanner

Reverb chamber 0.8-18 GHz



Managing the spectrum of the platform

Frequency Spectrum before and after modification



Memory clock/strobe collisions in the radio bands (GDDR5)

Memory Strobes with 1.5% SSC	GSM 869-894MHz	GSM900 925-960MHz	WCDMA (III) 1805-1880MHz	WCDMA (II) 1930-1990MHz	WCDMA (I) 2110-2170MHz	GPS 1572-1577MHz	WiFi/BT 2.4-2.48GHz	WiMax 2.3-2.7GHz
400Mbps =100MHz	Yes	No	Yes	Yes	Yes	Yes	No	Yes
600Mbps =150MHz	Yes	No	No	Yes	No	No	No	Yes
1000Mbps =250MHz	No	No	No	Yes	No	No	No	Yes
1600Mbps =450MHz	No	No	No	Yes	No	Yes	No	Yes
2200Mbps =550MHz	No	No	No	No	Yes	No	No	No
2600Mbps =650MHz	No	No	No	Yes	No	No	No	Yes
3400Mbps =850MHz	No	No	No	No	No	No	No	Yes
3800Mbps =950MHz	No	Yes	Yes	No	No	No	No	No
4200Mbps =1050MHz	No	No	No	No	No	No	No	No
4600Mbps =1150MHz	No	No	No	No	No	No	No	No
5000Mbps =1250MHz	No	No	No	No	No	No	No	Yes

Frequency planning aids in intelligently picking the right memory clock frequency and spread settings that will result in minimal RFI impact across all radio bands

Widely varying RFI impact to multiple radios

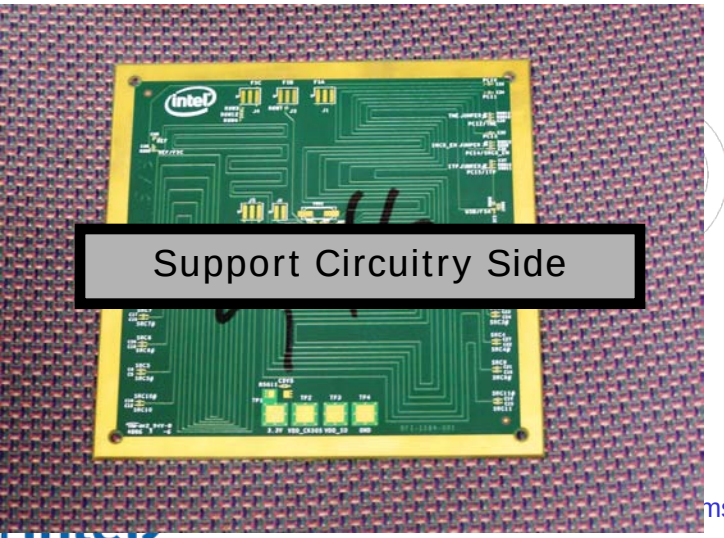
Static Frequency Planning Pros & Cons

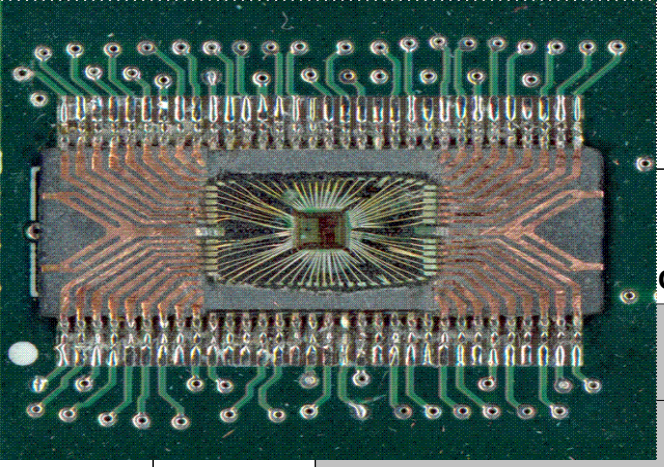
- Relatively Simple
  - No additional components and/or materials
  - Good if you own the complete ‘stack’ (hardware/software/product)
- If Harmonics are separated by less than the span of the wireless band, one peak is traded for another
  - Trading an even for odd harmonic still might be OK
  - Difficult to remove harmonics entirely
- Gets tougher to make it work with more than 1 radio and/or wireless specs with multiple bands
  - GSM/WCDMA
  - Simultaneous usage models are emerging
- Some system frequencies cannot be changed

One tool but by no means a silver bullet

Measurement Methodology-GTEM

- Repeatable
- Easy to use
- Cost ~ $12k
- Test board separate package from support circuitry

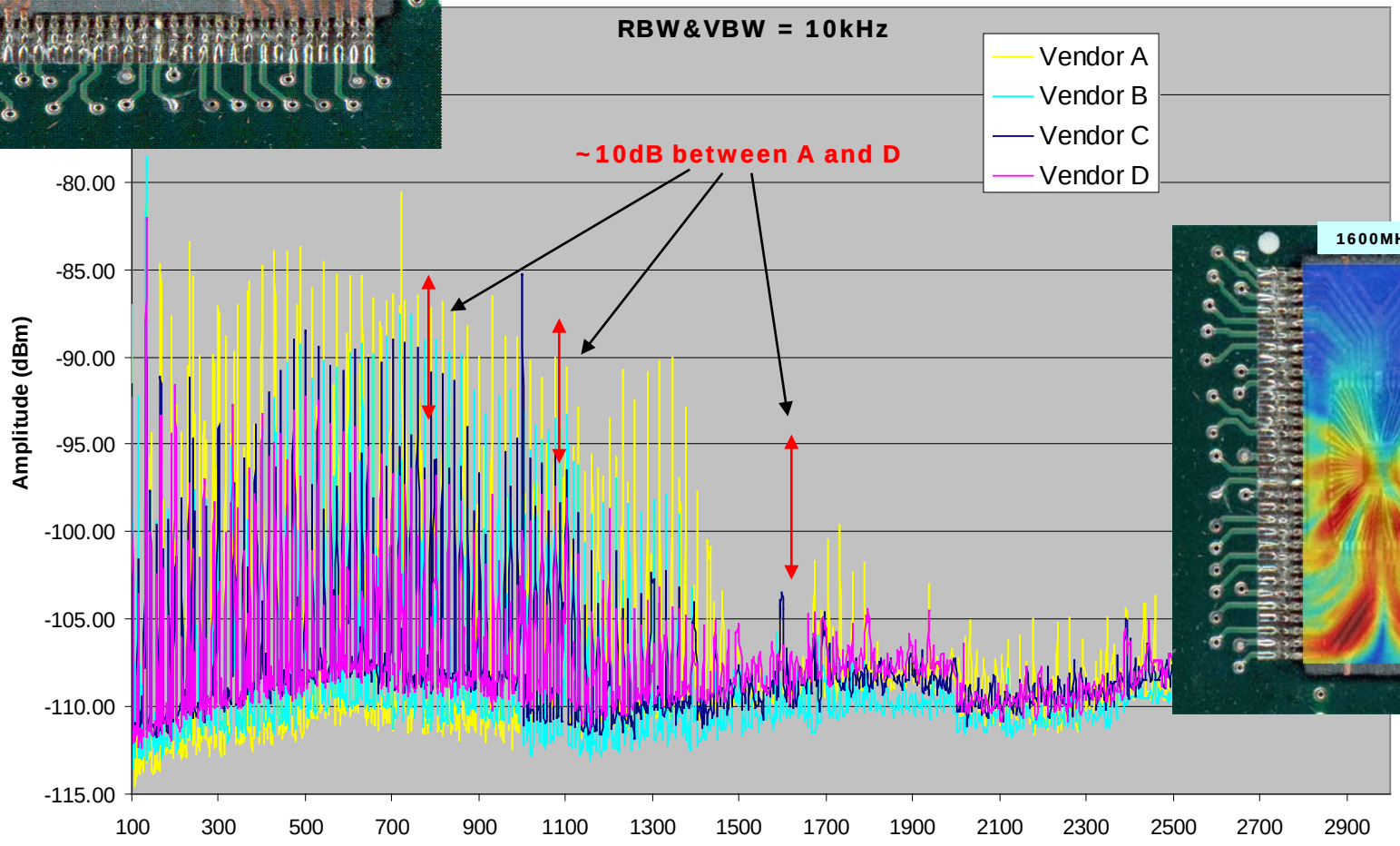


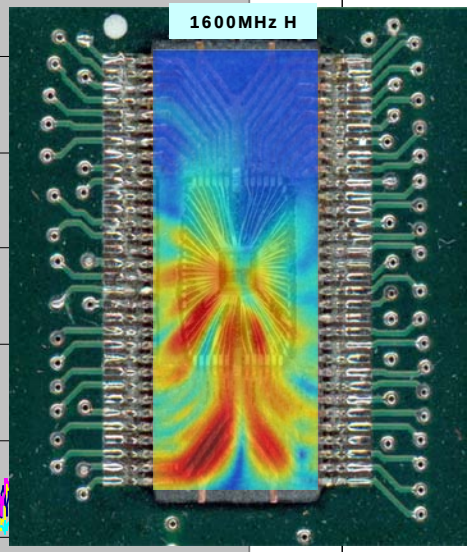


GTEM Capture of 166MHz BSEL Mode

CK505 64pin TSSOP package on 4" test board

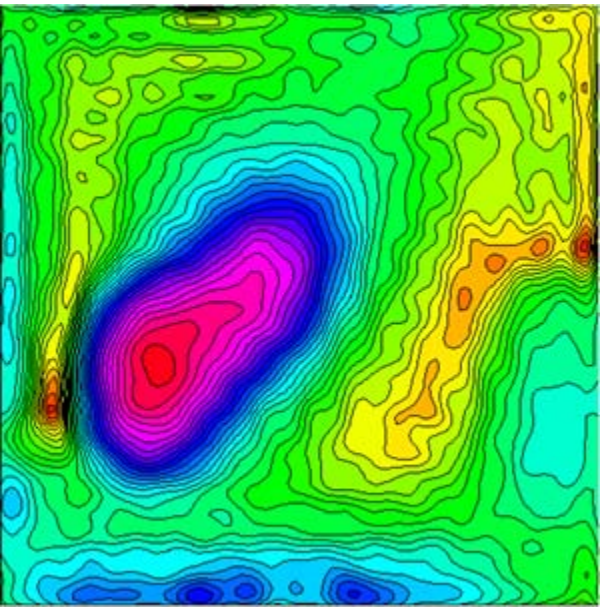
RBW&VBW = 10kHz





Need to control this variation

1 GHz

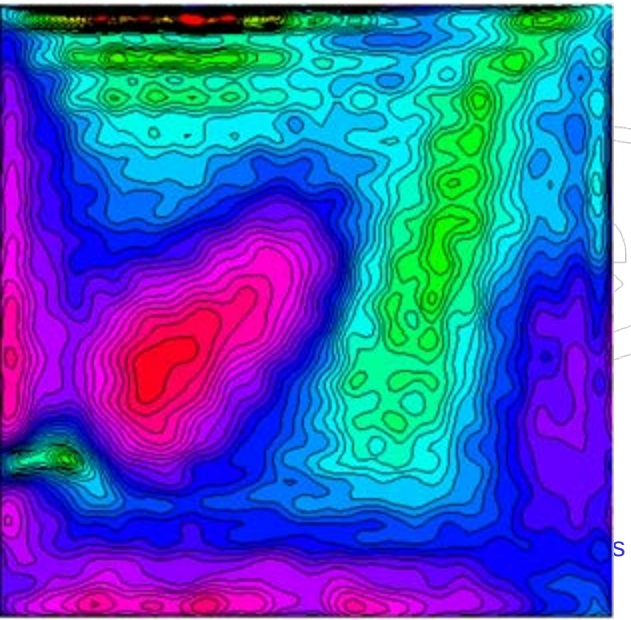


$f_E(x,y)_{1GHz}$

measured

Interpolated surfaces
From discrete measurements

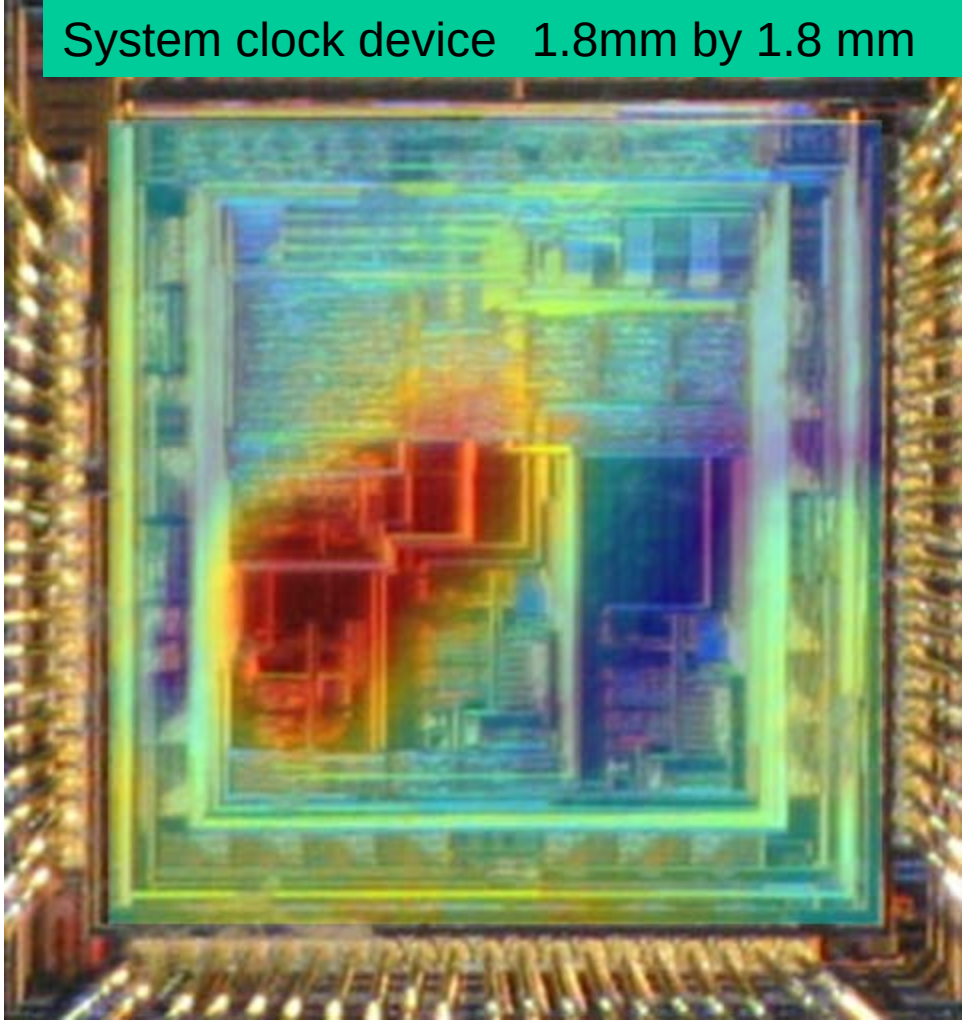
3 GHz



$f_E(x,y)_{3GHz}$

measured

System clock device 1.8mm by 1.8 mm



$$\begin{bmatrix} m_{11} & m_{12} & \dots & m_{1n} \\ m_{21} & m_{22} & \dots & m_{2n} \\ \dots & \dots & \dots & \dots \\ m_{n1} & m_{n2} & \dots & m_{nn} \end{bmatrix} \rightarrow f(x,y)$$

Discrete
Measurement
Matrix, step size = 50 um

Near Field Scans over die

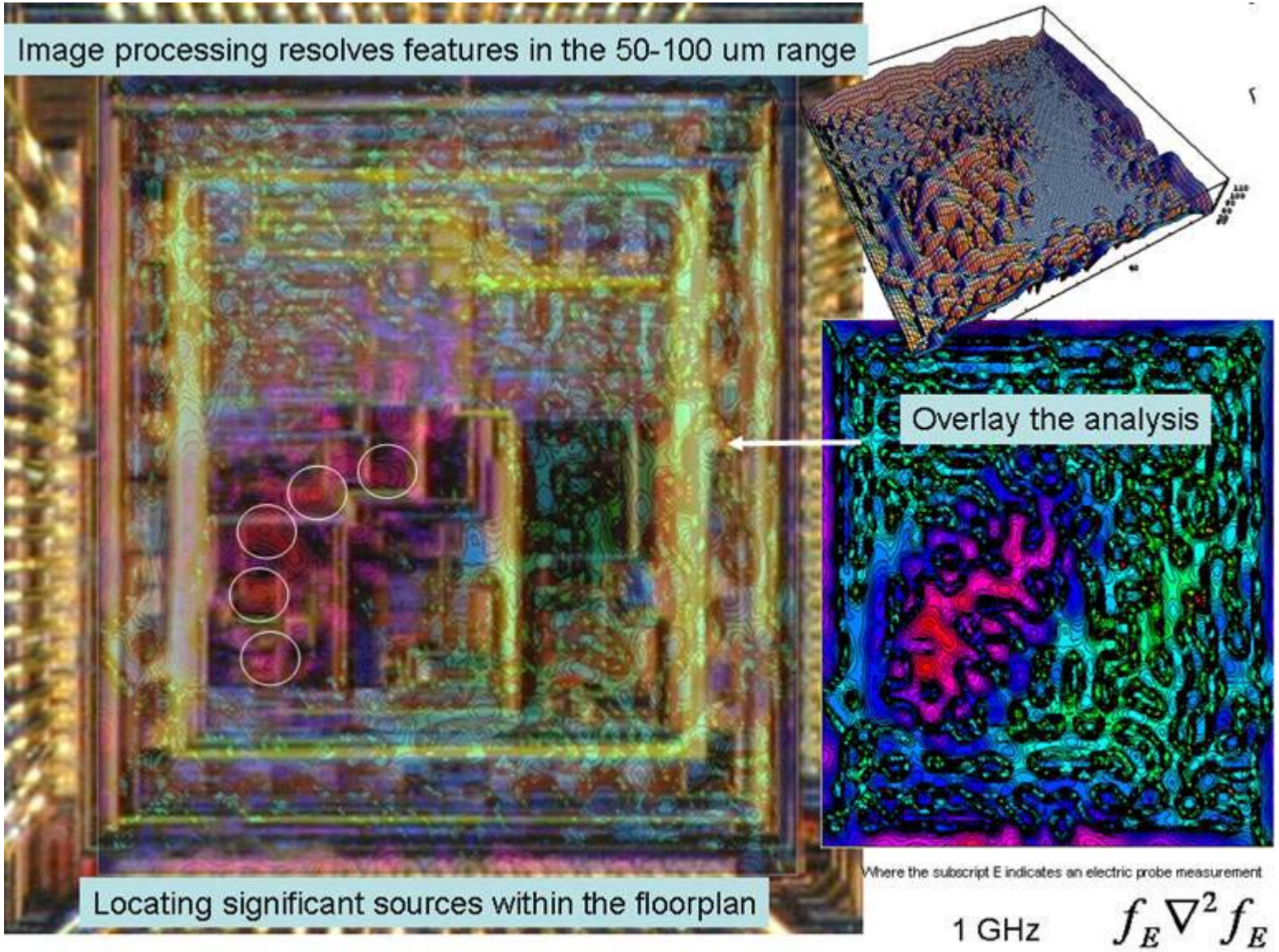
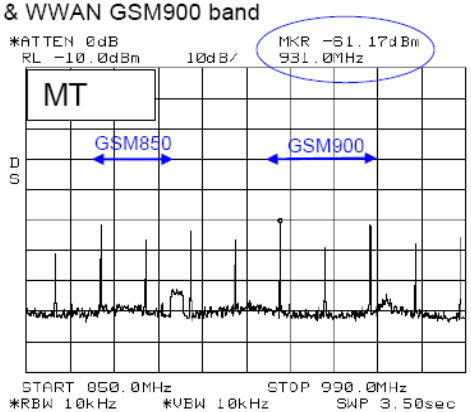


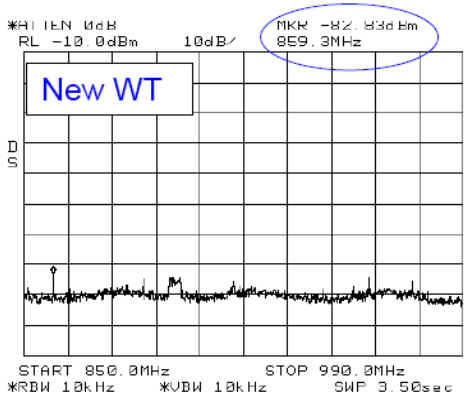
Image processing resolves features in the 50-100 um range
Overlay the analysis
Where the subscript E indicates an electric probe measurement
1 GHz
$f_E \nabla^2 f_E$
Locating significant sources within the floorplan

Key Results

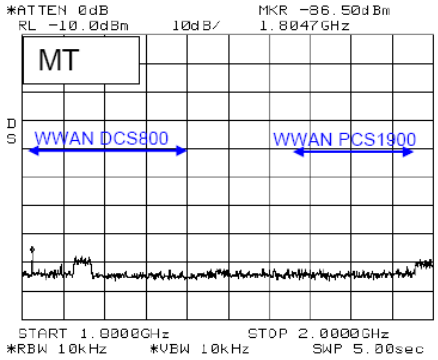
- Reported results (Jan 07) of a new CK505 part with improved RFI/EMI

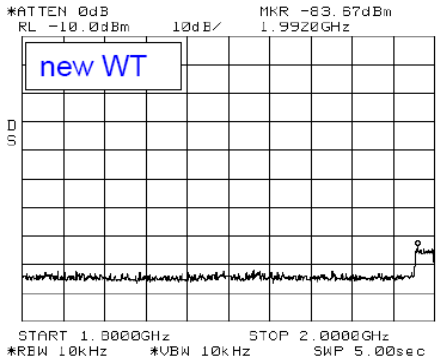
GSM850 & WWAN GSM900 band



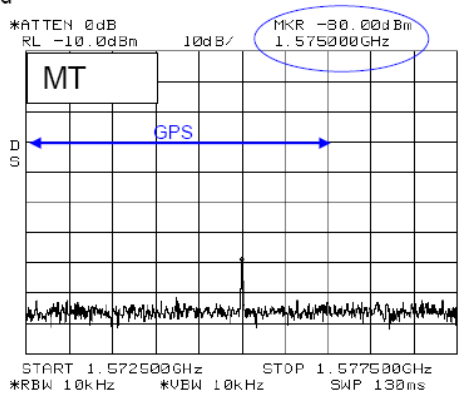


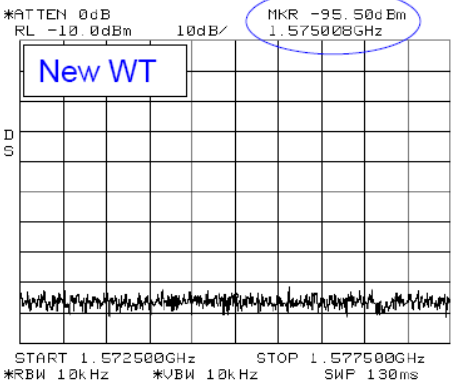
WWAN DCS1800 & PCS1900 band





GPS band





Significant improvements in radio bands

Impact of Results

Clock Supplier

- Quick-turn analysis of the clock chip early in development phase
- Better product solutions for OEM/ODM

OEM

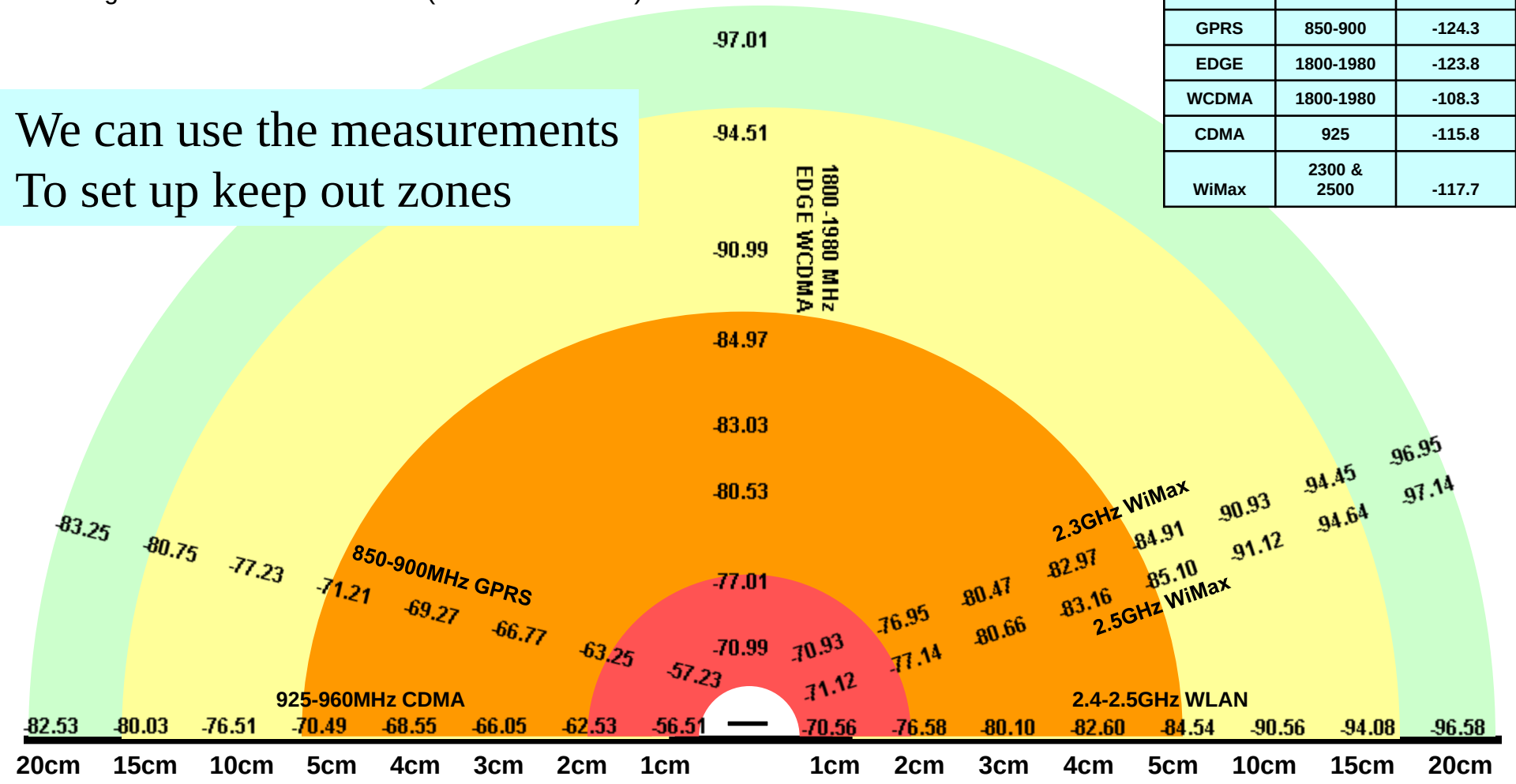
- Minimizes need for expensive after-the-fact shielding solutions
- Eases implementation of multi-radio mobile platforms
- Elimination of RFI at the source removes roadblocks to future innovative form factors

Isotropic Radiator

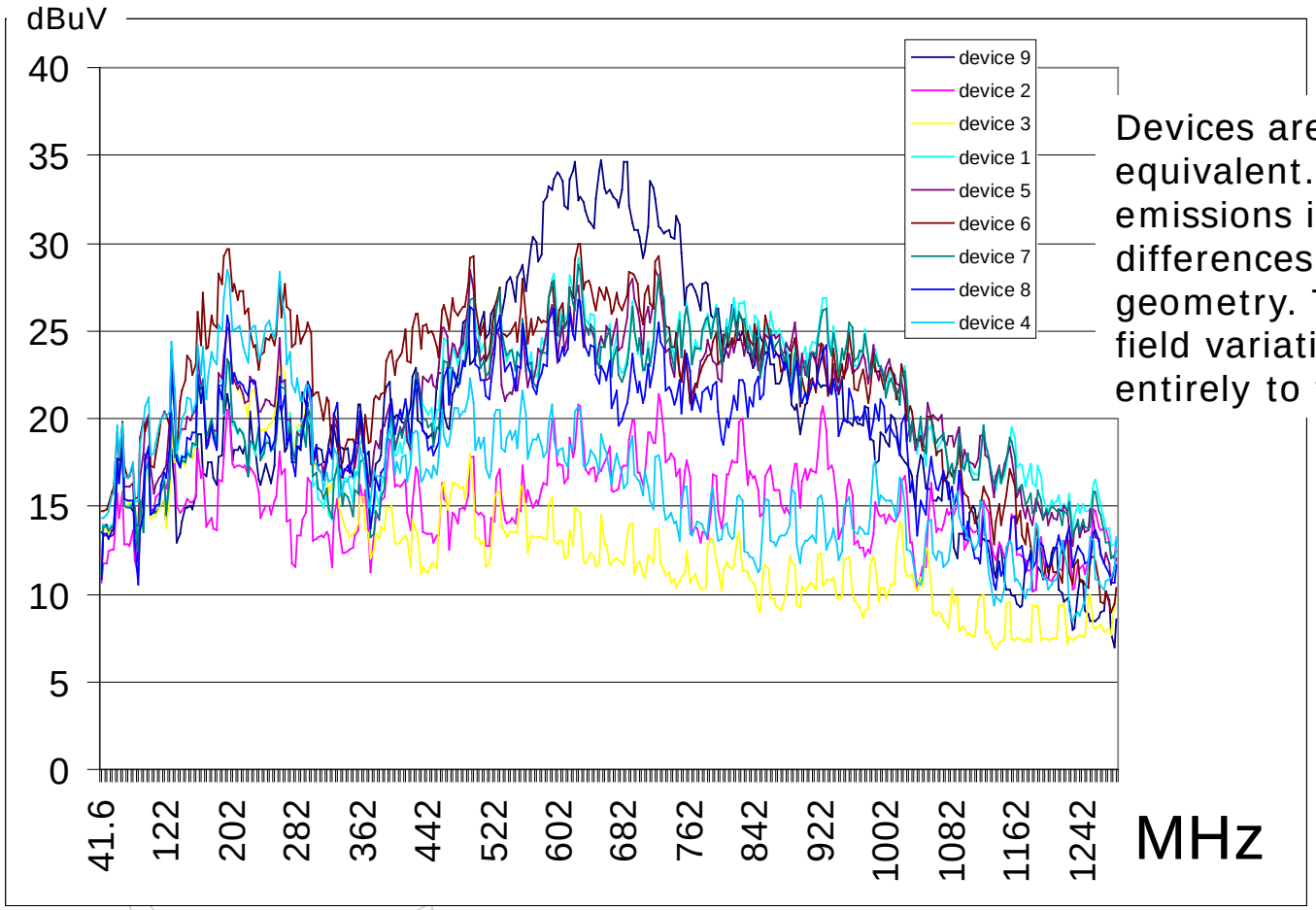
1. Scaling GTEM result for distance
2. Avg value of 4 vendor data (not min or max)

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

We can use the measurements
To set up keep out zones



The measured GTEM emissions of 9 Pentium system clock devices.

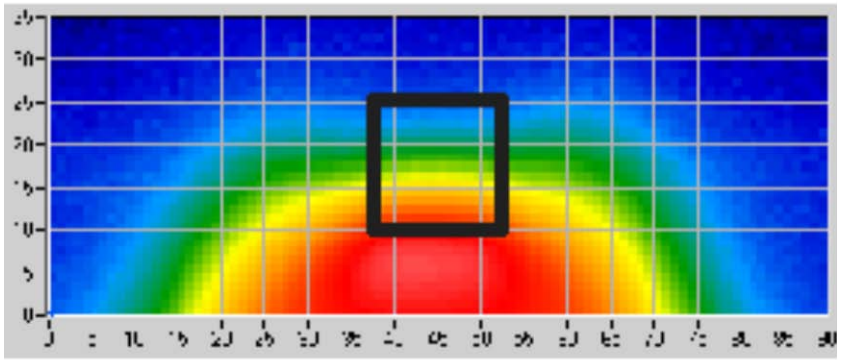


Devices are all functionally equivalent. No variation in emissions is due to software differences, or to lead frame geometry. Therefore, all field variations are due entirely to the silicon.

These spectra come from older devices and so have no spectral content above 1300 MHz. Newer devices have significant energy above 3 GHz.

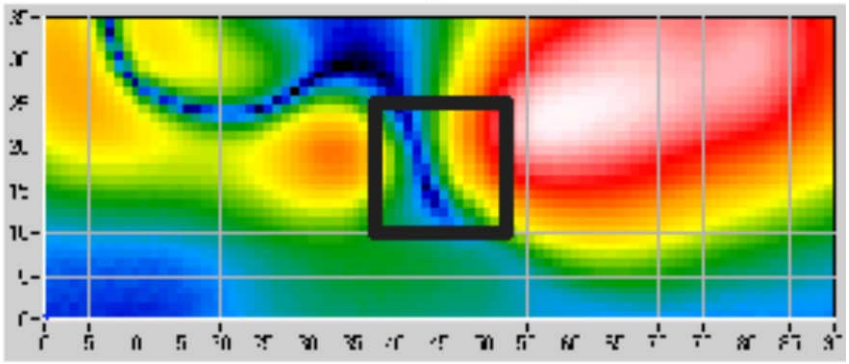
Near Field Scans of Clock IC

Electric field over package surface

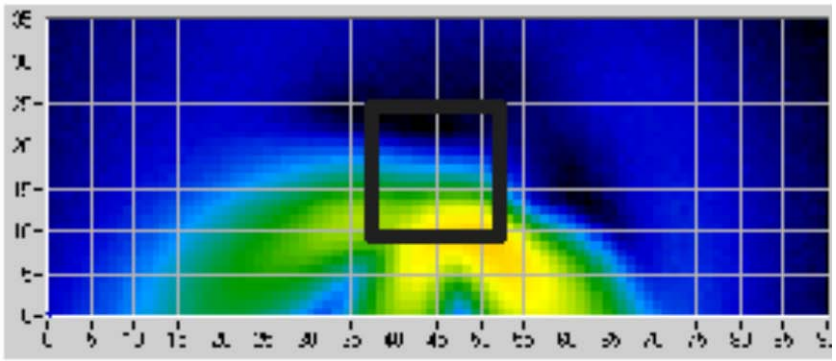


frequency = 33 MHz

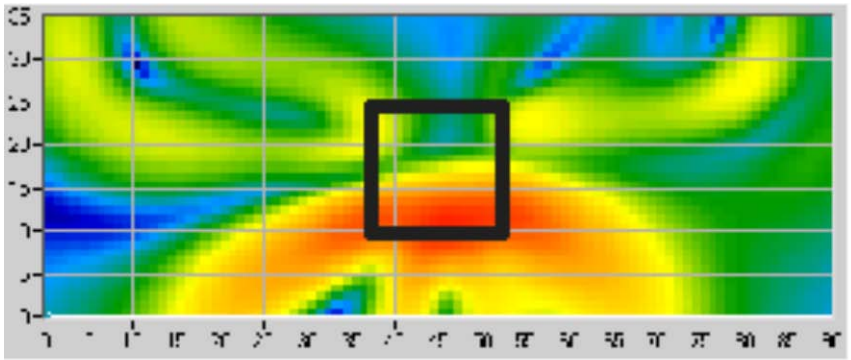
Electric field over package surface



frequency = 66 MHz



Magnetic field over package surface

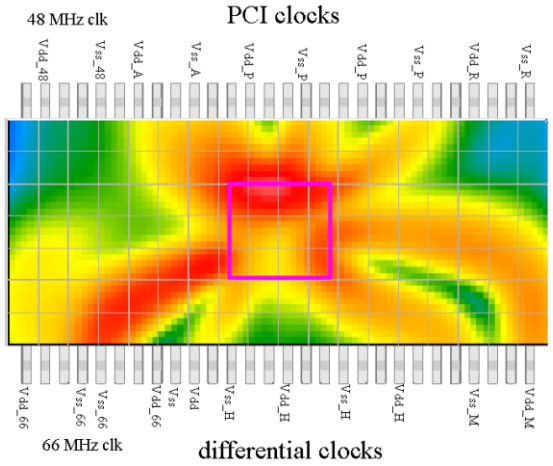


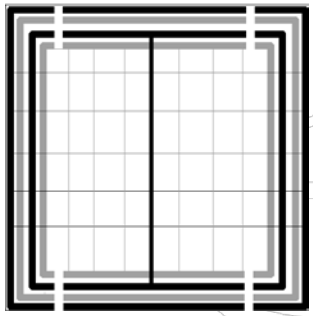
Magnetic field over package surface

A comparison of the near fields from 3 manufacturers

Pentium® 4 Clock devices

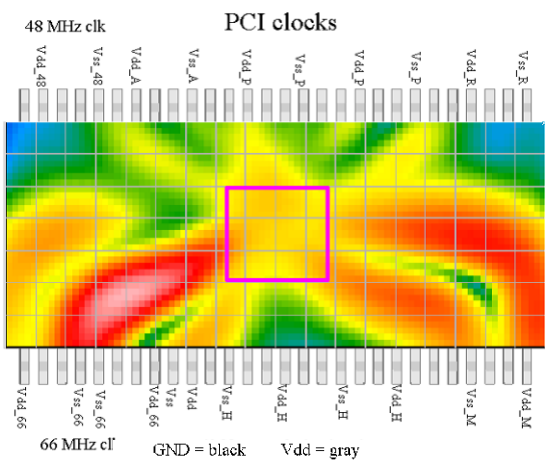
Manufacturer 1

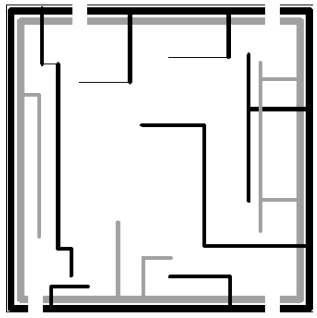




Symmetric Vdd/Vss

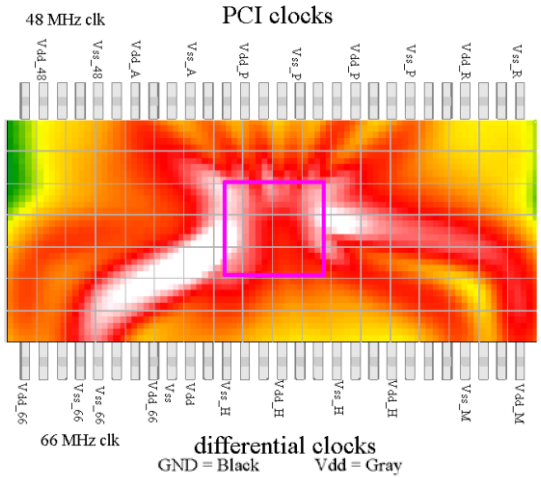
Manufacturer 2

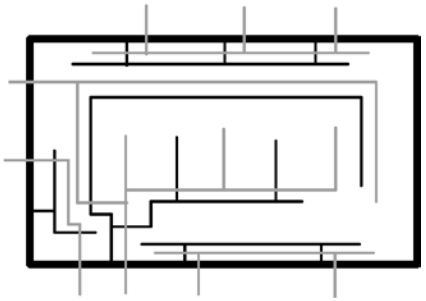




Comparing Vdd/Vss distribution effects

Manufacturer 3





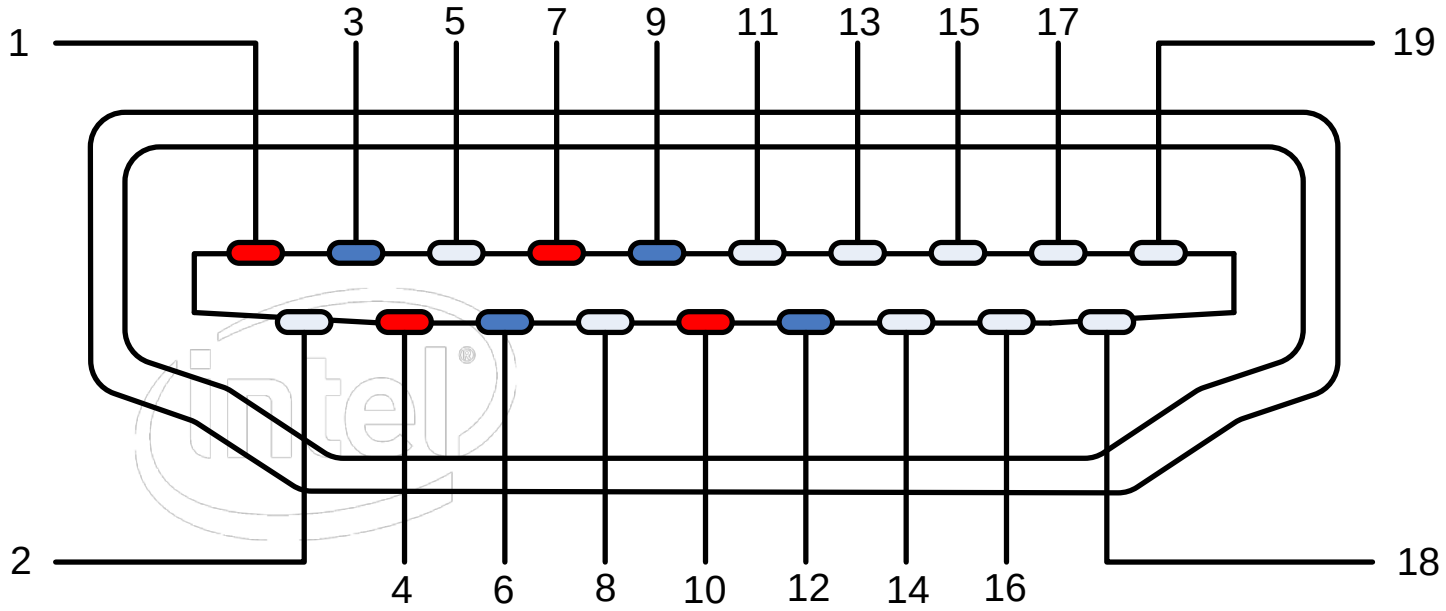
asymmetric Vdd/Vss

Up to 12 dB variations in radiated emissions were seen between manufacturers

Effects of changing the position of the clock pair

The 4 possible positions for the clock pair are:

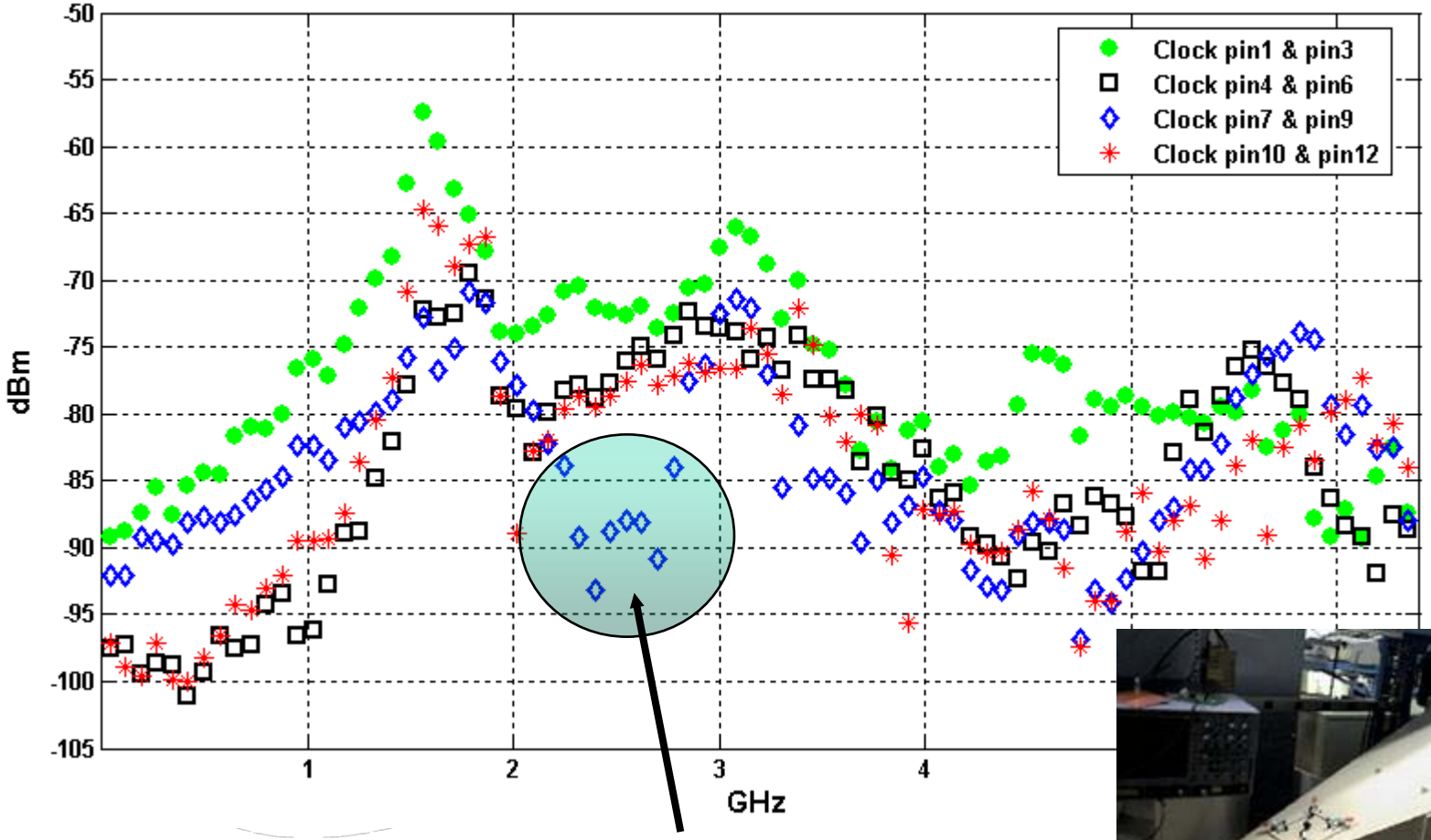
- pins 1 and 3
- pins 4 and 6
- pins 7 and 9 and
- pins 10 and 12.



The pin assignment of the HDMI connector showing the position of the 4 differential pairs

38MHz Clock

Pin assignments in high speed interconnects can be crucial to lower interference



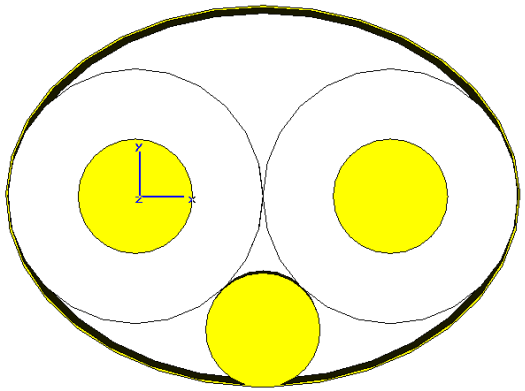
GTEM

Measured in the VLSI GTEM

802.11b/g band

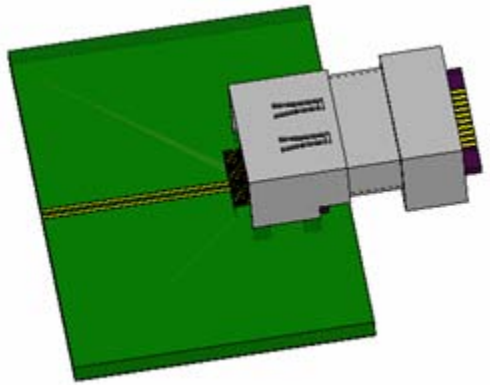
Where does skew come from?

- Length mismatch
- Change in material properties
- Losses
- Differential output at Tx



What EMI effects does it have?

- Cable:
- Connector:
  - Connector itself
    - Differential traces



Effects of change in ε_r on cable EMI

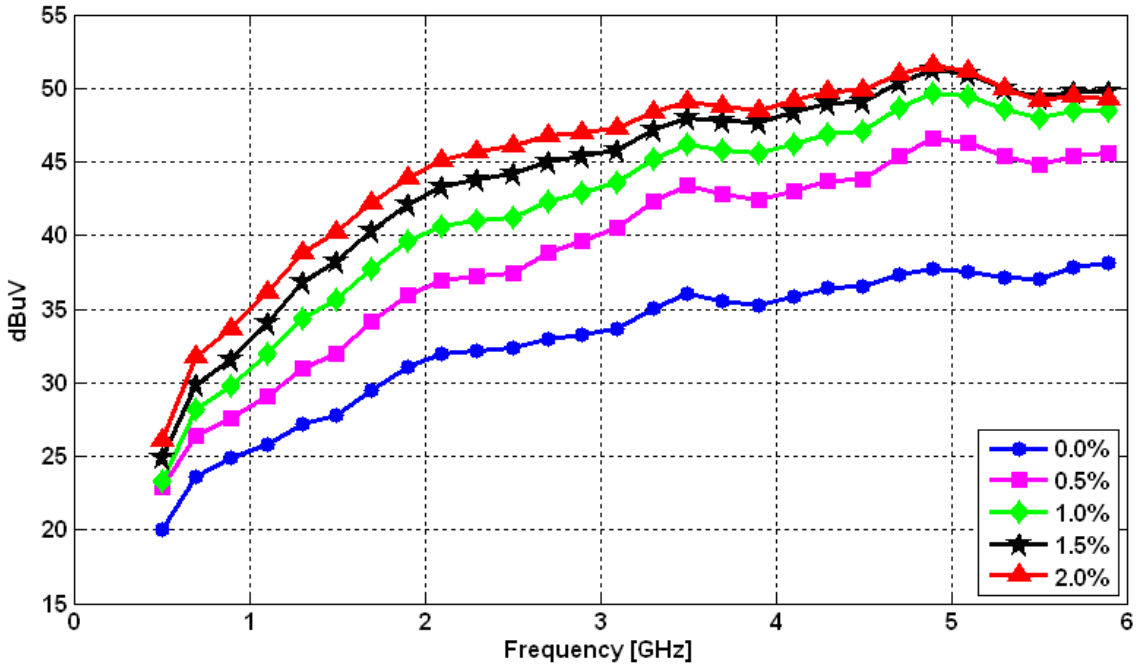
$$c_{dielectric} = \frac{c}{\sqrt{\varepsilon_r}};$$

$where\, c = speed\ of\ light;$

$\varepsilon_r = relative\ permitivity$

The skew is for % change of ε_r over the length of 3m

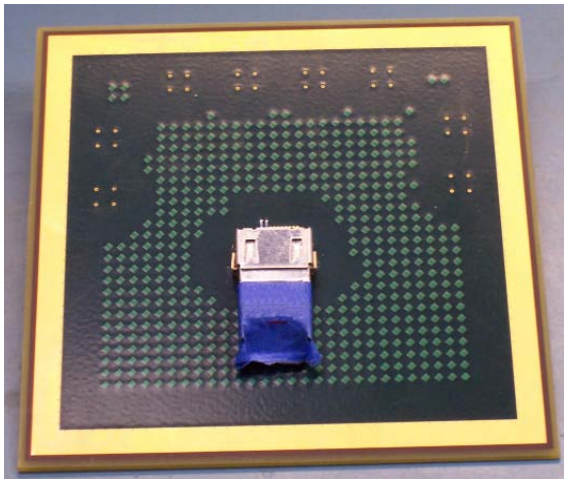
Er	% change	Skew(ps)
2.080	0.00	0.0
2.085	0.25	18.0
2.090	0.50	36.0
2.096	0.75	54.0
2.101	1.00	71.9
2.106	1.25	89.9
2.111	1.50	107.8
2.116	1.75	125.6
2.122	2.00	143.5



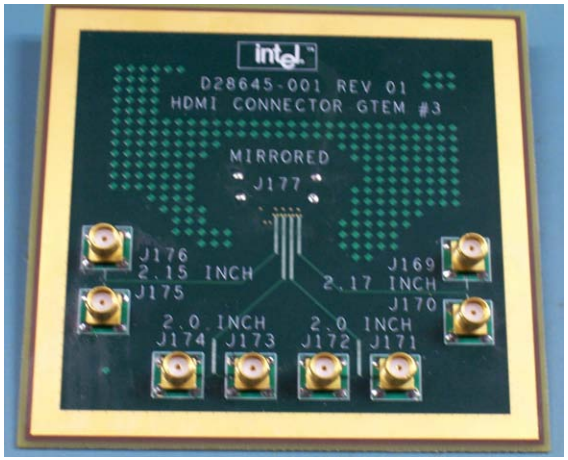
Plot of the EMI as a function of % change in ε_r of the insulation material for the last 50cm of a 3m cable

GTEM measurements

Giga hertz Transverse Electro-Magnetic Cell



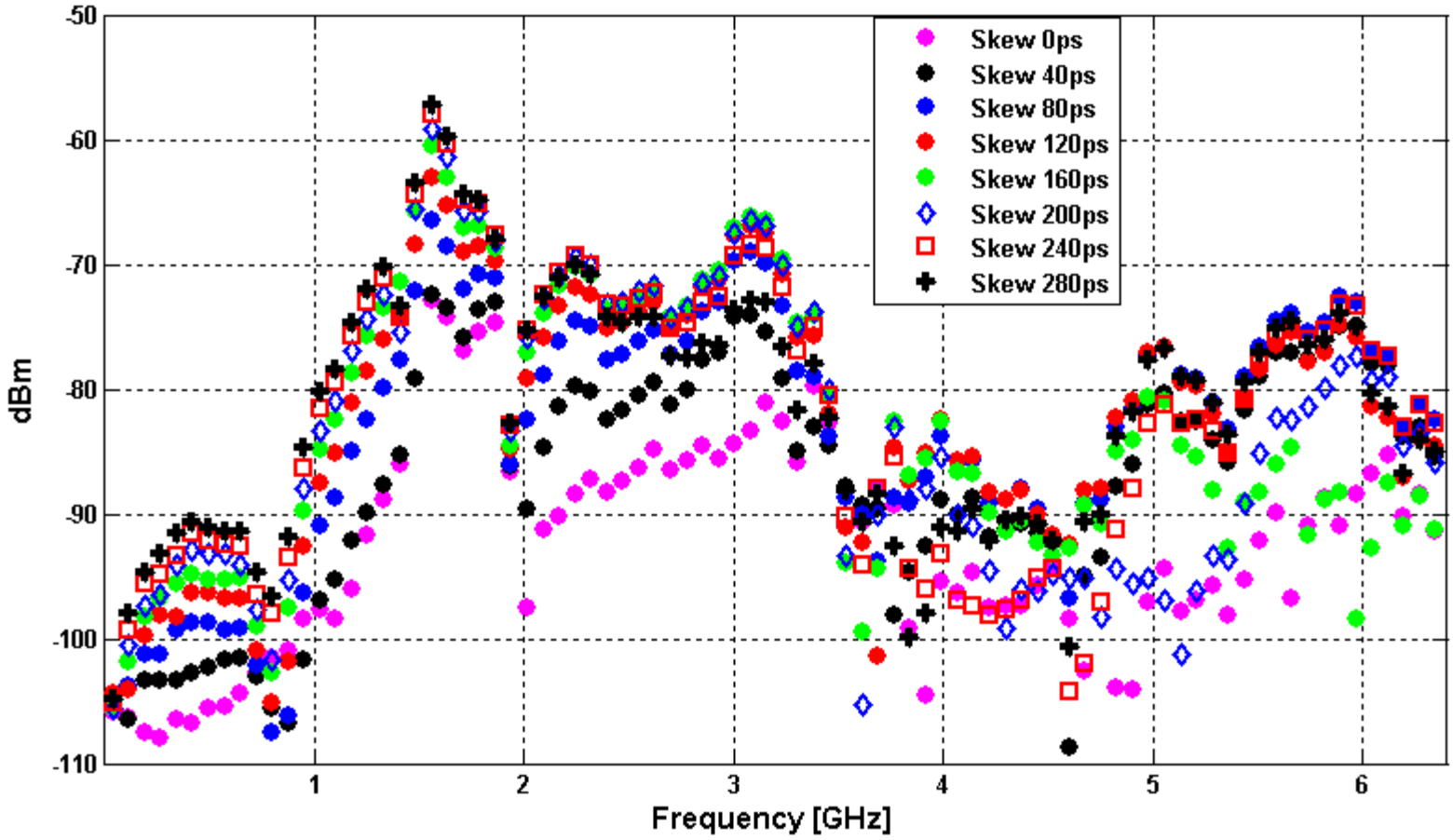
(a)



(b)

The GTEM test PCB showing (a) the HDMI connector (receptacle and plug) on one side that faces the inside of GTEM cell and (b) supporting traces and connectors on the other side

Effects of skew on EMI



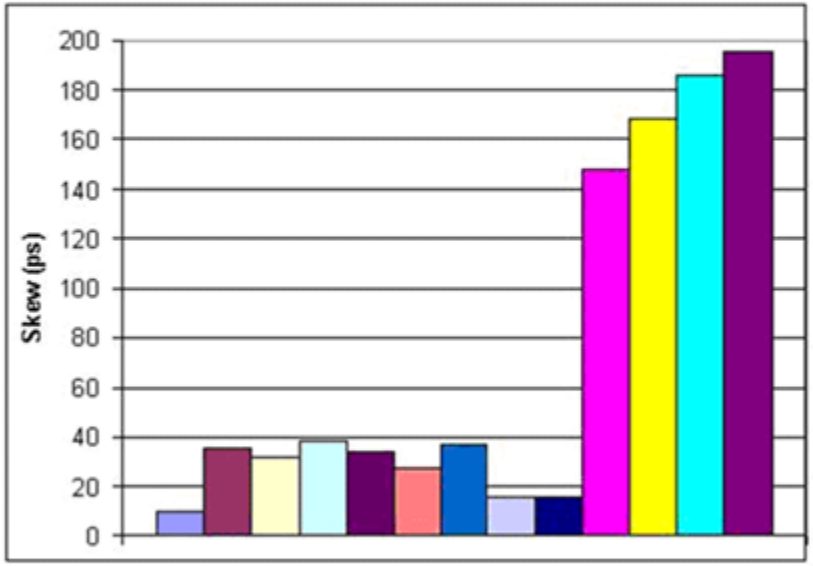
Pin10(D+) & Pin12(D-) fed with a 38MHz clock

Off the shelf

3 meter cables

Cables Measured	Skew in ps
1	70
2	58
3	74
4	150
5	46
6	10
7	78
8	36
9	32
10	72

Cable skew

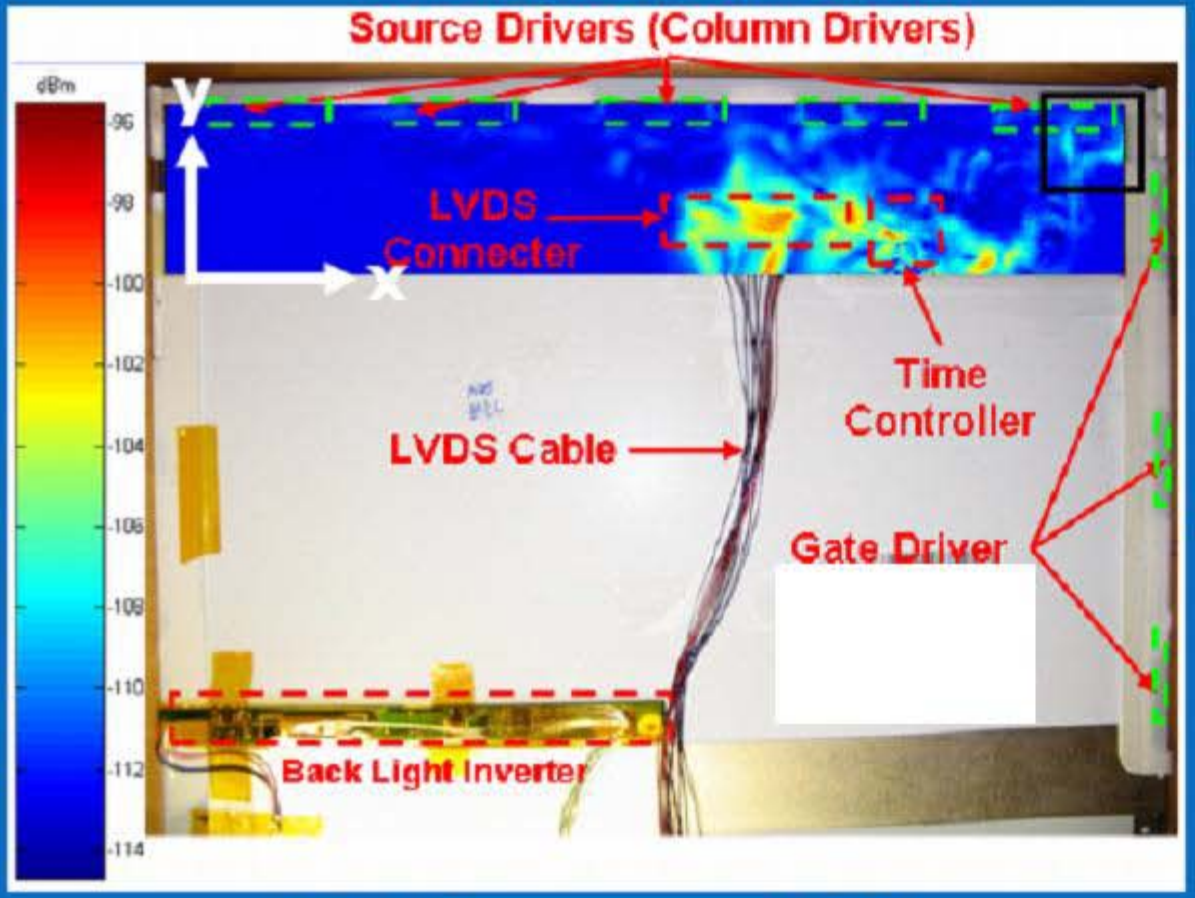


- Standard HDMI cables w lock cutouts
- Standard/IDC/Crimp (without lock cutouts)
- Standard IDC/Soldering
- Standard/Soldering/Crimp
- Standard/Soldering/Soldering
- Double Braid + twinax/IDC/Crimp
- Double Braid + twinax/IDC/Soldering
- Double Braid + twinax/Soldering/Crimp
- Double Braid + twinax/Soldering/Soldering
- Double outside shield/IDC/Crimp
- Double outside shield/IDC/Soldering
- Double outside shield /Soldering/Crimp
- Double outside shield/Soldering/Soldering

Skew is now becoming part of cable specifications

Identification of Major EMI Sources on LCD Panel

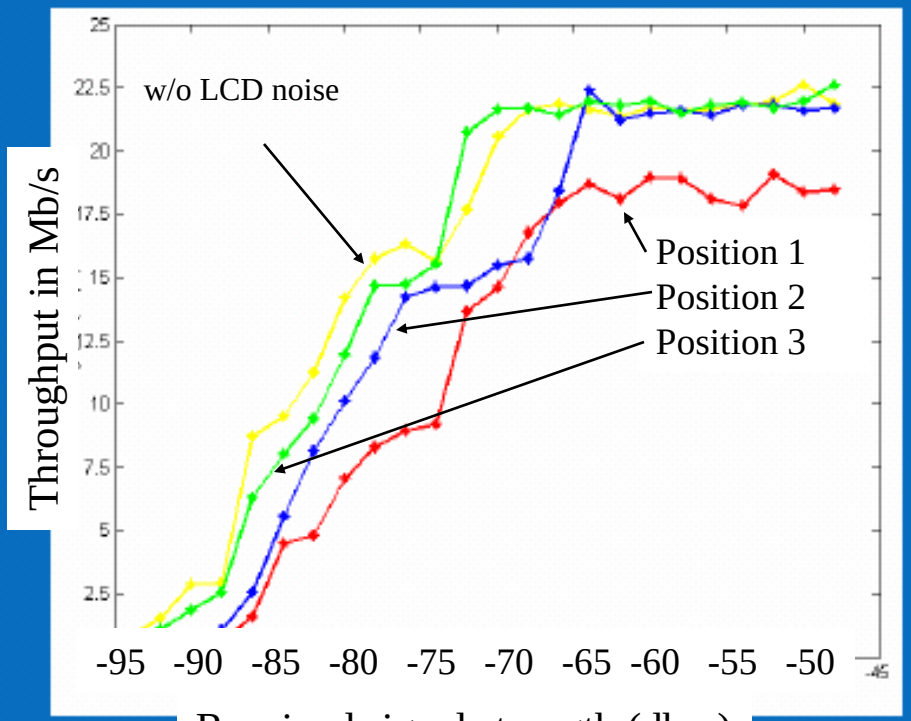
- H-field scanning in Frequency Domain at 2.410GHz

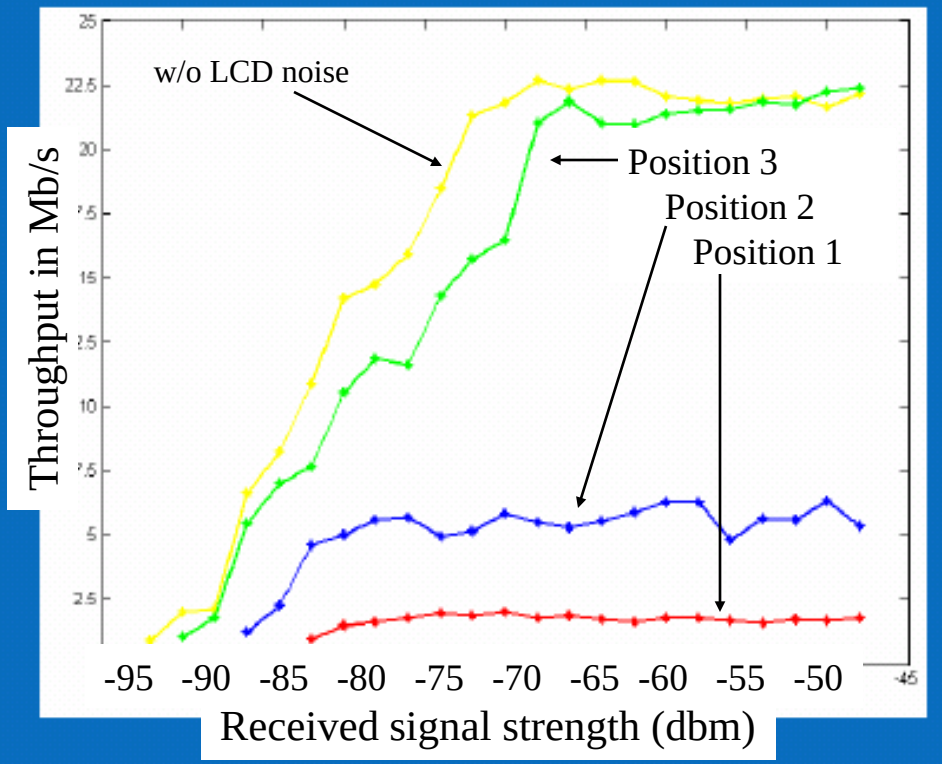


1. LCD panel scanned is a 15.0" panel.
2. The scanning area (the light blue zone) is 300 x 55mm. The scanning plane is parallel to the driving circuit with a vertical standoff of 3mm. The scanning step is 0.5mm along both X and Y axes as defined in this slide.
3. The H-field scanning measurement shown reveals that the LVDS connector, LVDS cable and the TICON are the strongest EMI sources compared to other devices (such as gate, source drivers) amounted on the driving circuit.

15.0" LCD

A Throughput Comparison at Three Different Positions





Antenna Placement Conclusions

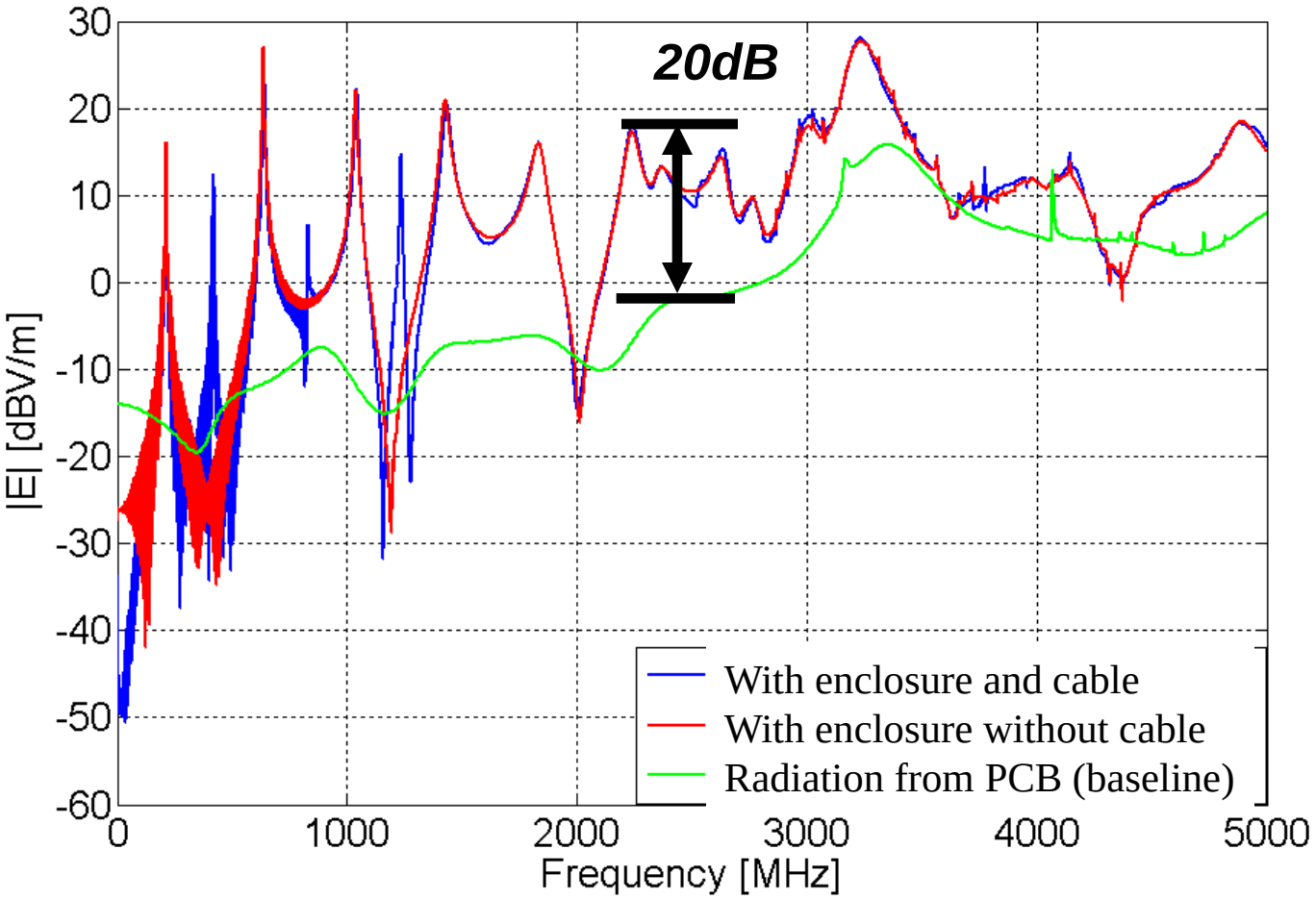
- Noise from row and column driver appears to be root cause of noise picked up by antenna
- Locating antenna away from row/column drivers will consistently help reduce EMI
- Location of antenna can sometimes, but not always, make a significant difference in EMI pickup
- Mitigation effectiveness has a wide range – from 1-2 dB up to more than 15 dB
- Antenna placement benefit will differ from notebook to notebook. Some cases will be successful while others may not be.
- Consider each solution a “point” solution

Resonance Issues: LCD RFI Emissions

- LCD RFI has been studied experimentally where the LCD enclosure was removed
  - » RFI energy comes out from the LVDS connector and cable, time controller, gate and source drives
  - » Gate and source drivers are the locally dominant sources even though LVDS connector, cable and time controller have much stronger signals
  - » Coupling between interference source and receiver decreases as the distance between them increases
- What is missing?
  - » Enclosure creates resonant structure
  - » Resonance leads to amplification of coupling between interference source and receiver
  - » Simple simulation shows that resonance could increase coupling by 20 dB

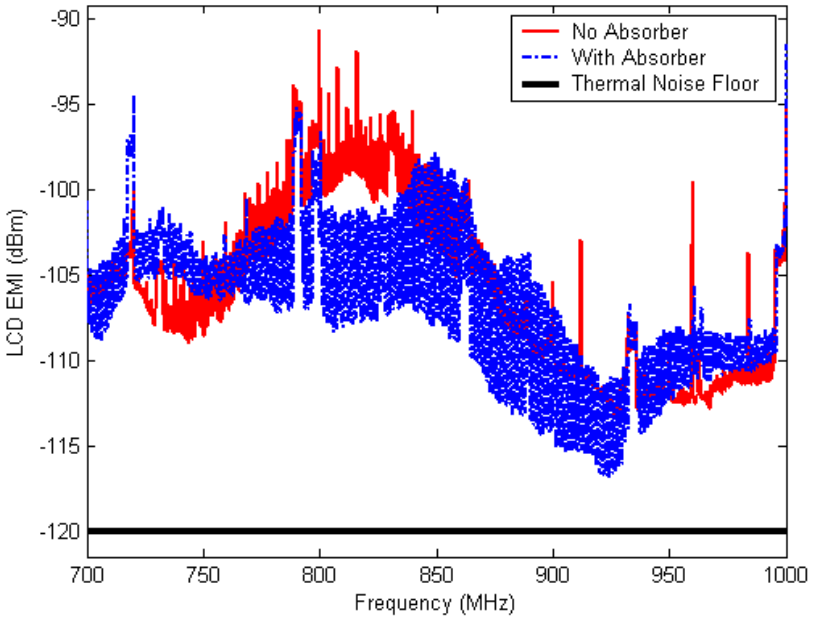
Resonance leads to Amplification

Influence of Enclosure

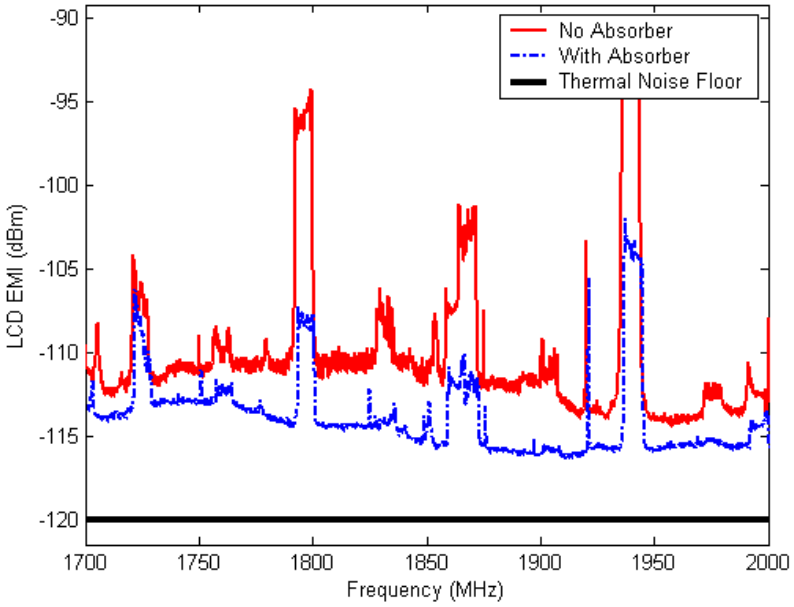


Resonance causes much stronger coupling

Mitigation Results for platform 1



Poor performance 700-1000 MHz



Significant improvement (>10dB) 1700-2000 MHz

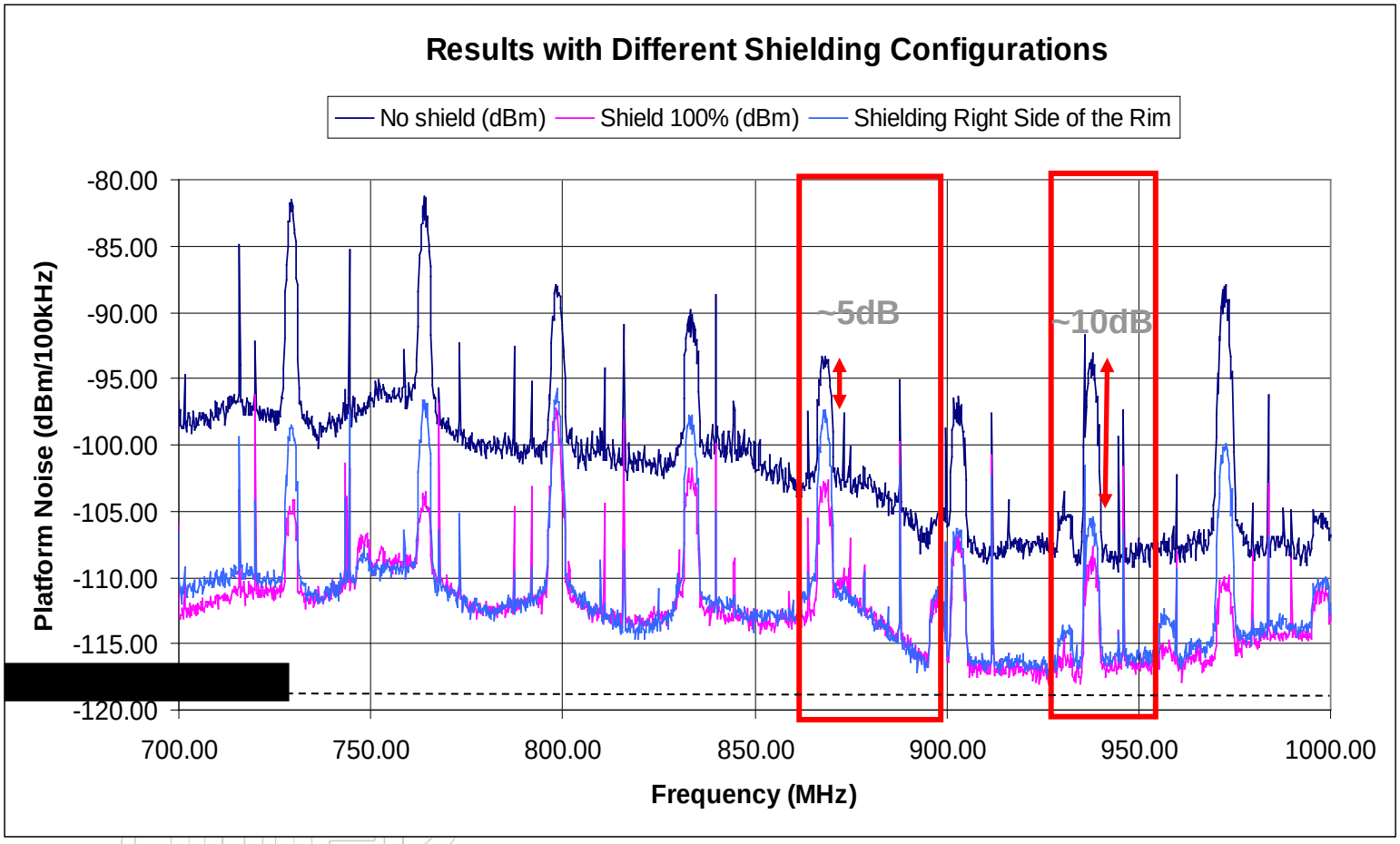
Absorber only performed well in higher band

Shielding Experiments (con't)

P-1 with full shielding

P-1 with shielding in only right side rim

Shielding Experiment Results



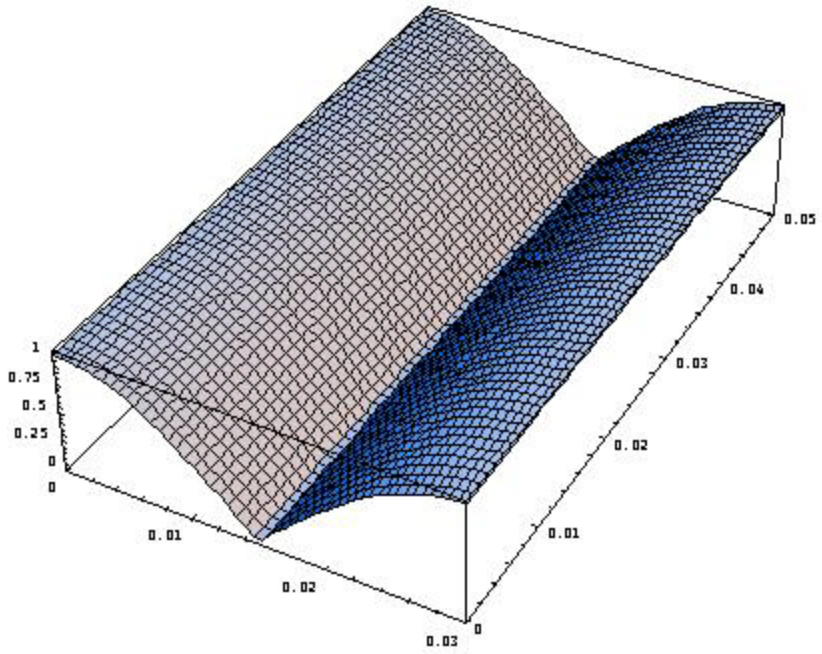
RX: GSM 850MHz GSM 900MHz

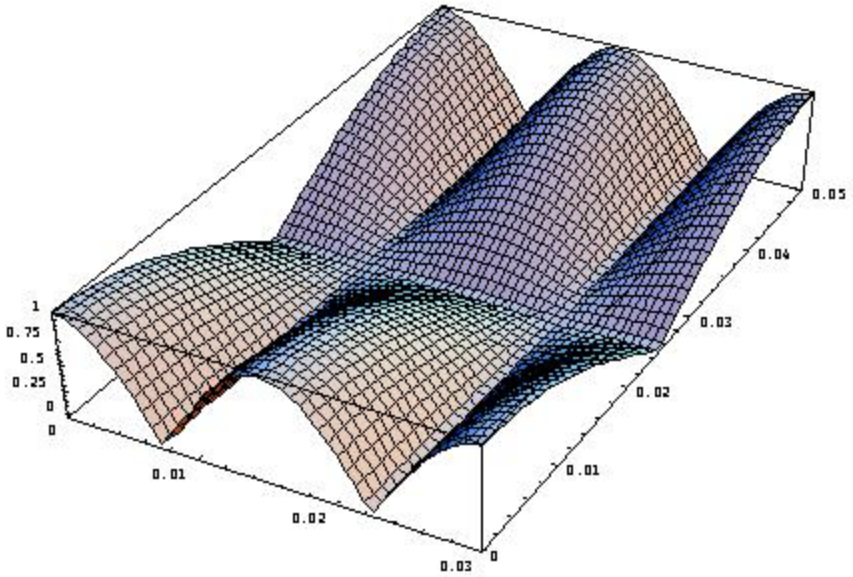
Shielding right side provides ~ 5-10dB mitigation. Concern: compromise of antenna performance (bandwidth and pattern) may occur unless separation is increased

mPCIe card

First resonant mode: m=1, n=0, Freq = 2.46 GHz

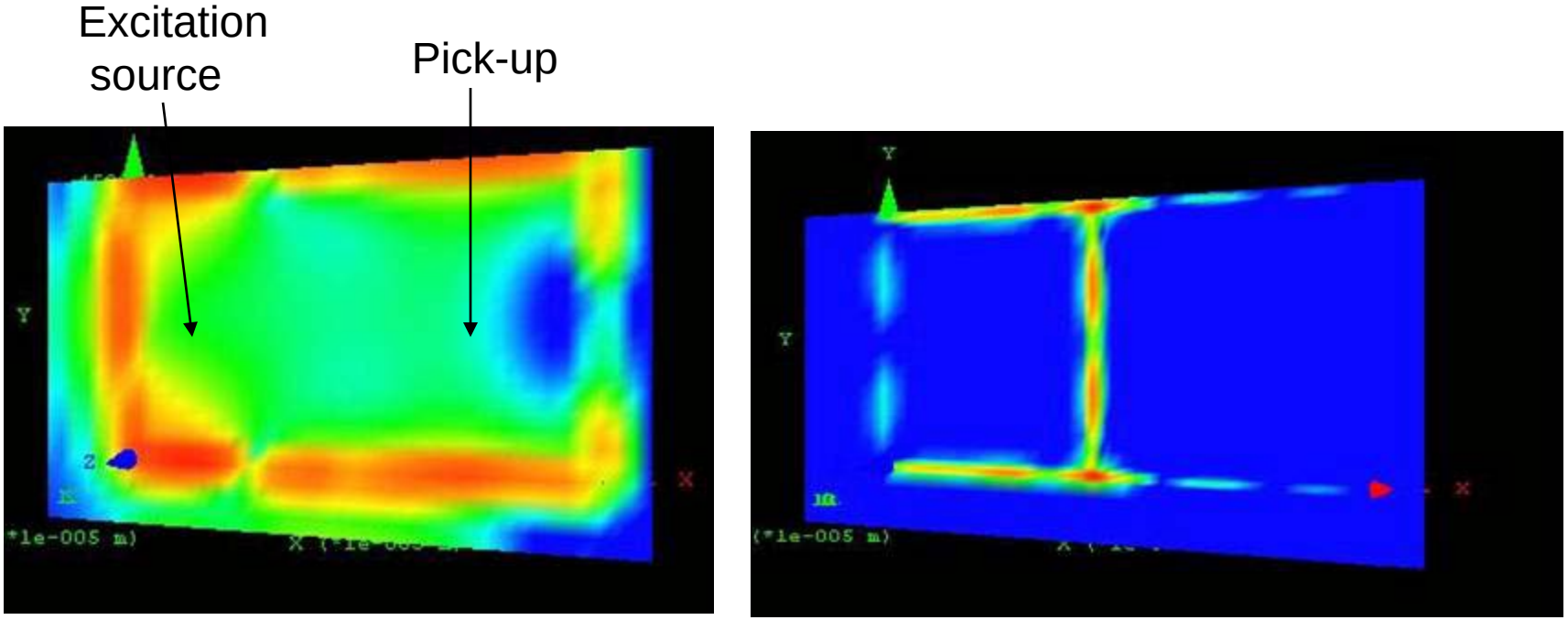
Higher order mode: m=2, n=1, Freq = 5.15 GHz





Analytical solution for power plane resonances using Mathematica (source: IEEE EMC Transactions, August 2003

PCB Models: Experimenting with isolation schemes
Achievable Isolation improvements: 4 layers

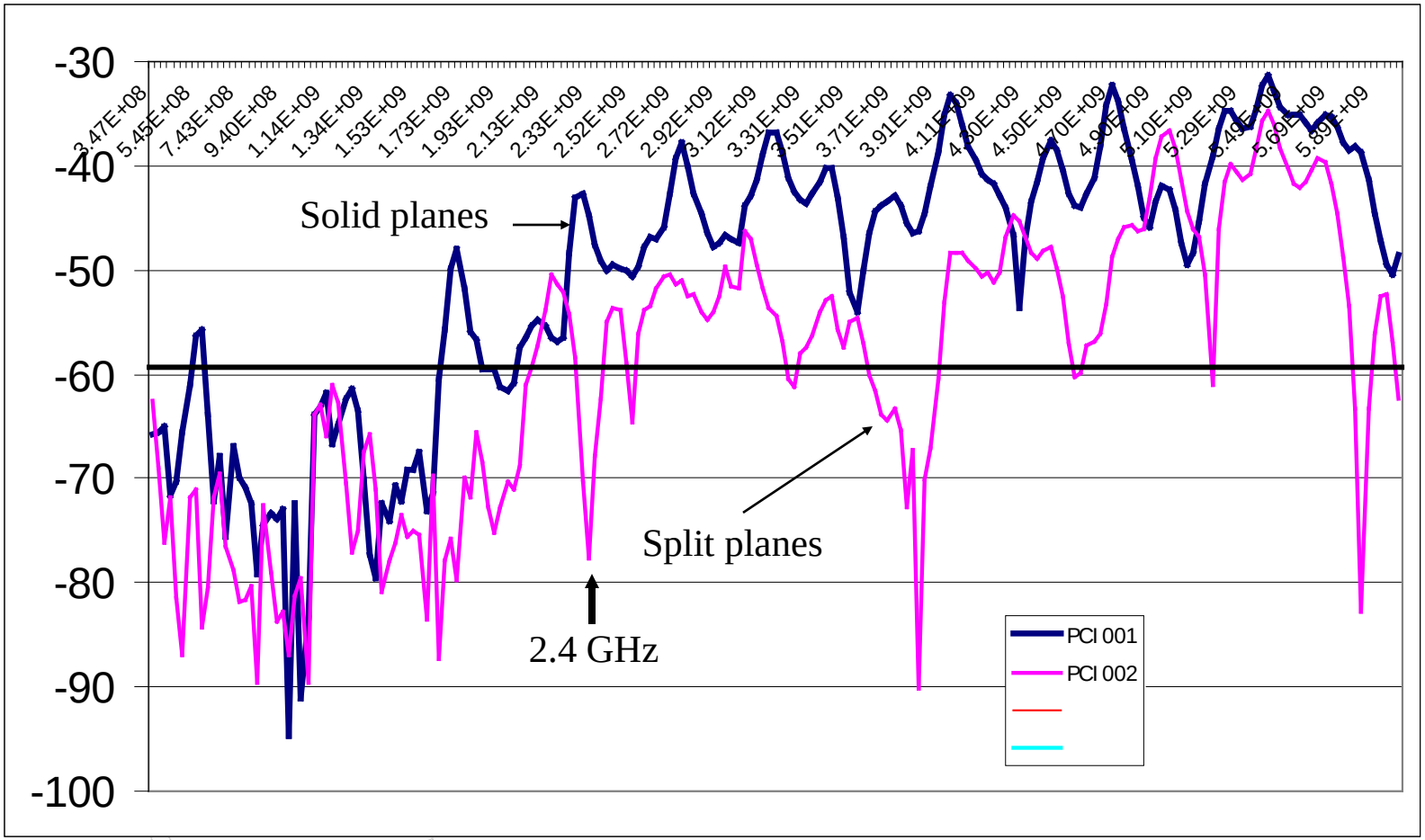


Solid Planes
20dB isolation

Split Power / Ground
50dB+ isolation

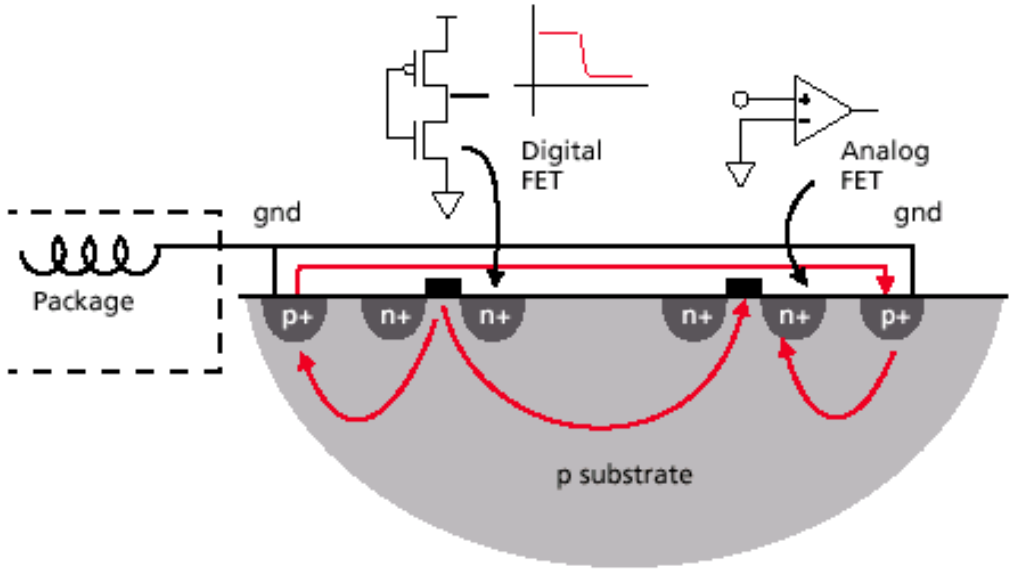
Significant isolation possible even with simple structures

Simulation Study Progress Report:



Experimental measurements of PCBs: Solid versus split planes- separating the digital from the radio power gains 10 dB of isolation on average and up to +30 dB in some ranges

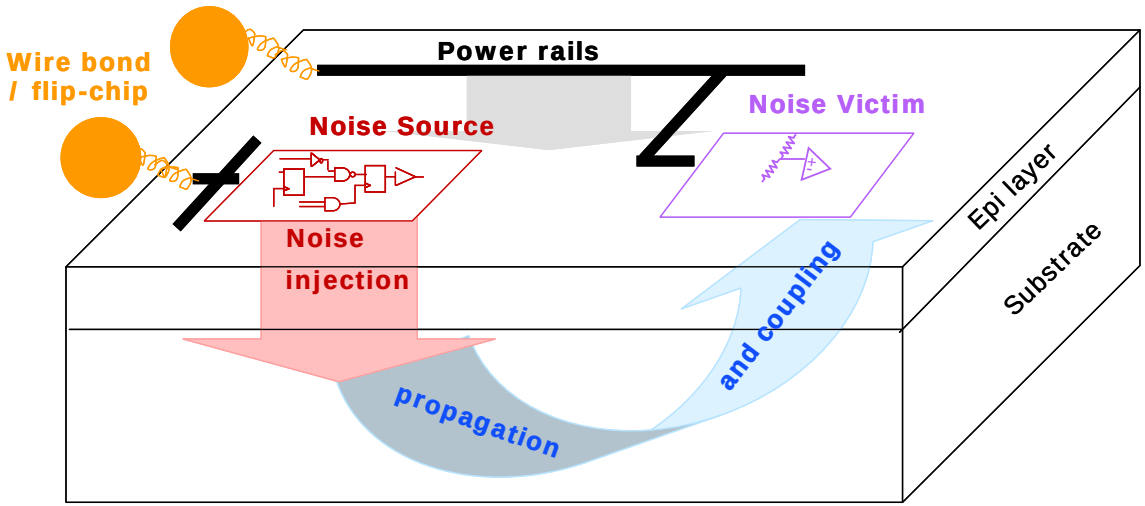
Finally, we can explore effects inside the silicon



Substrate noise coupling

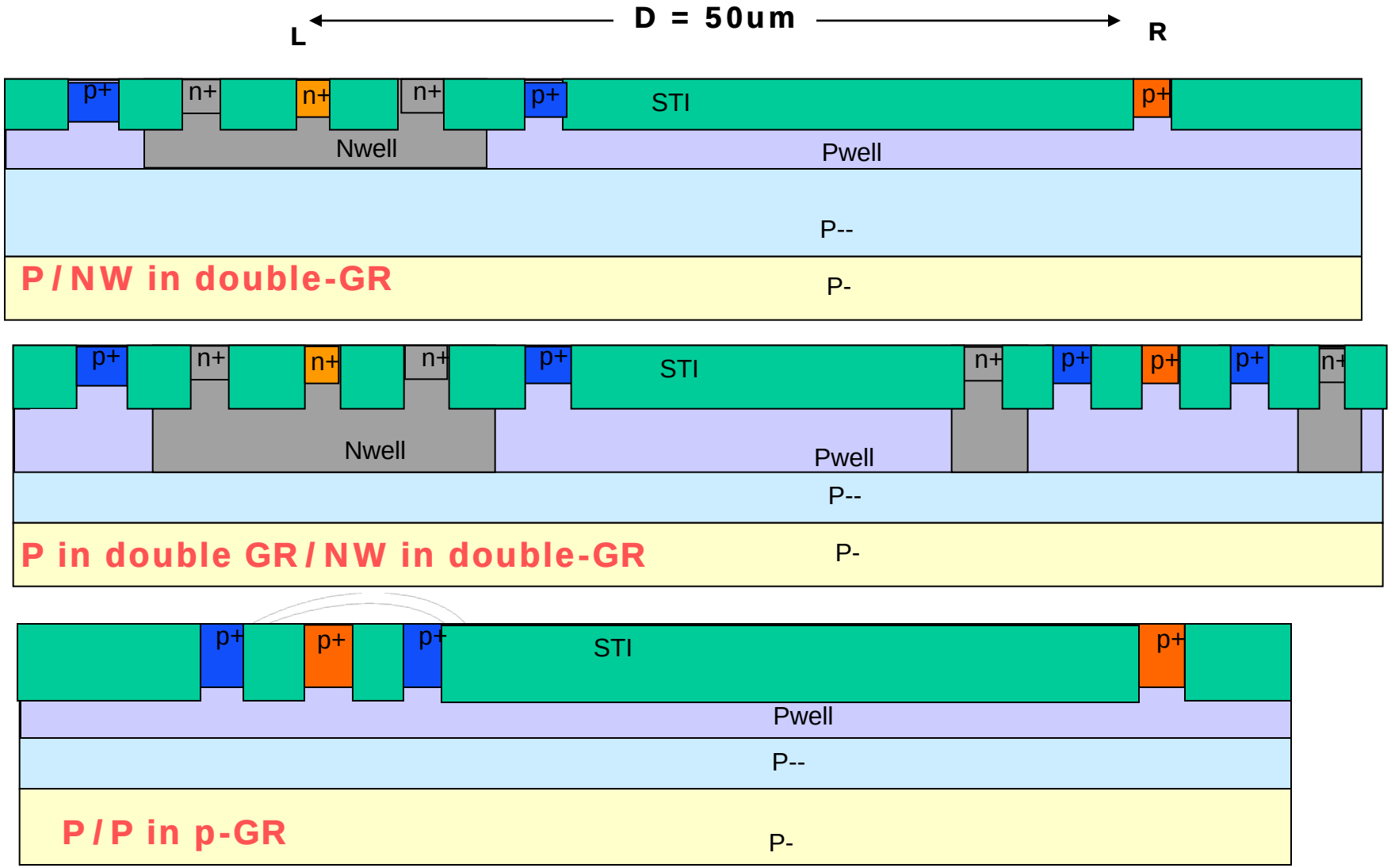
- **Device effect**
- **Package parasitics effect**
- **Interconnection effect**

Isolation in silicon structures

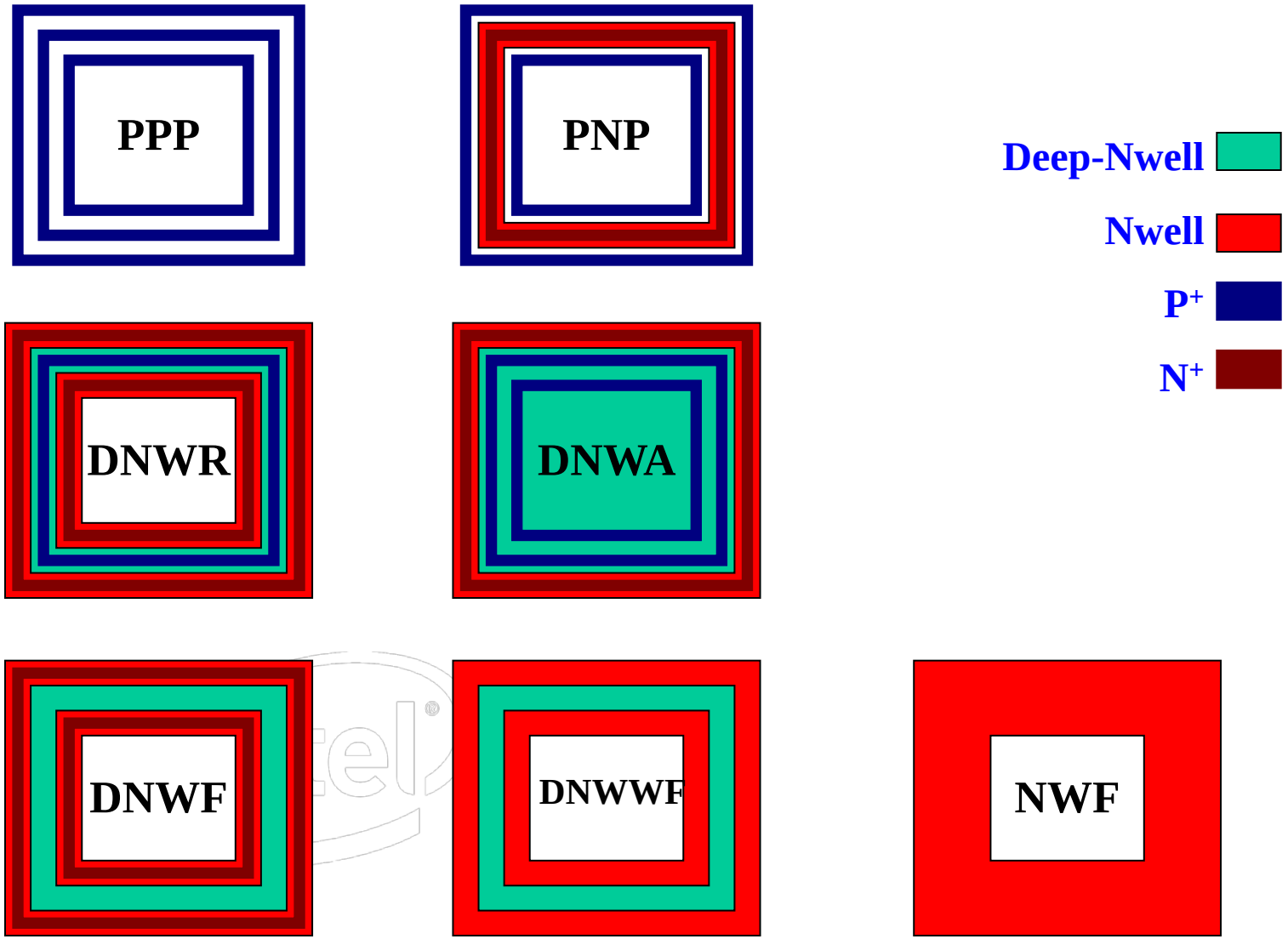


Silicon integration involves putting radio and digital systems onto the same substrate.
An understanding of the substrate noise coupling (SNC) is therefore important.
SNC will set the isolation performance and determine the impact.
The above figure shows the basic mechanism of substrate noise coupling.
SNC is largely influenced by process technology as well as layout design.

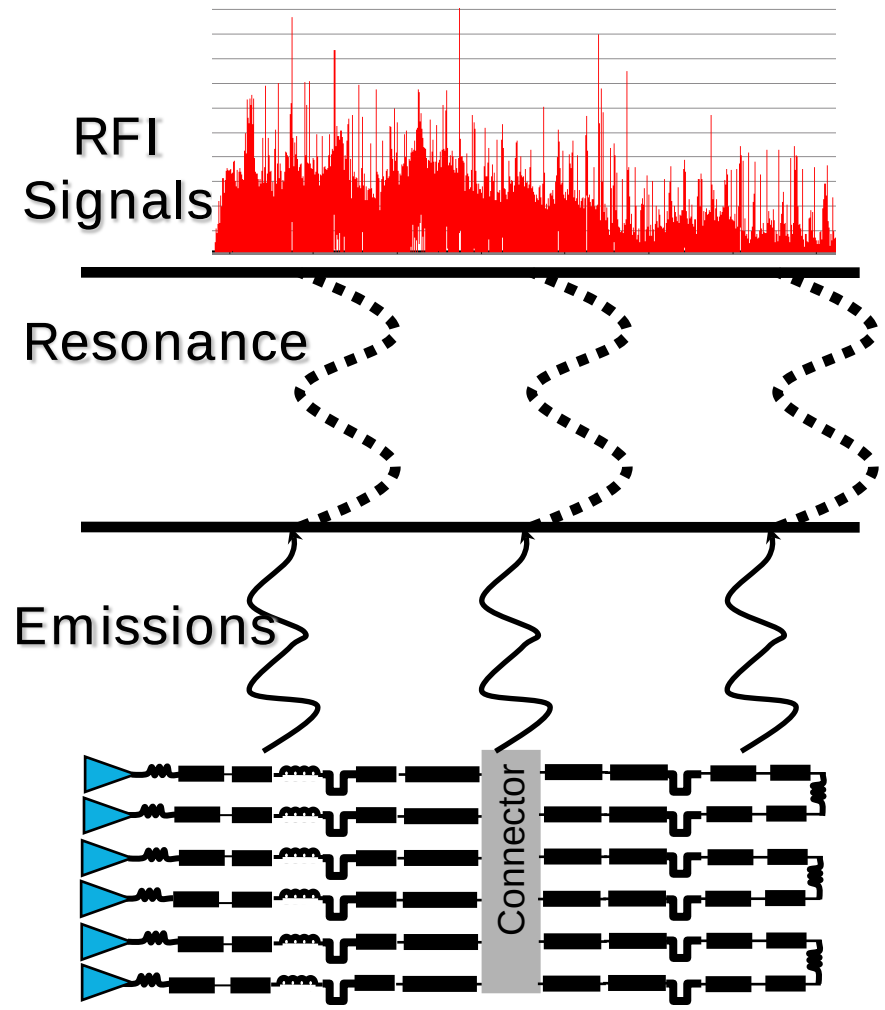
Different guard ring structures

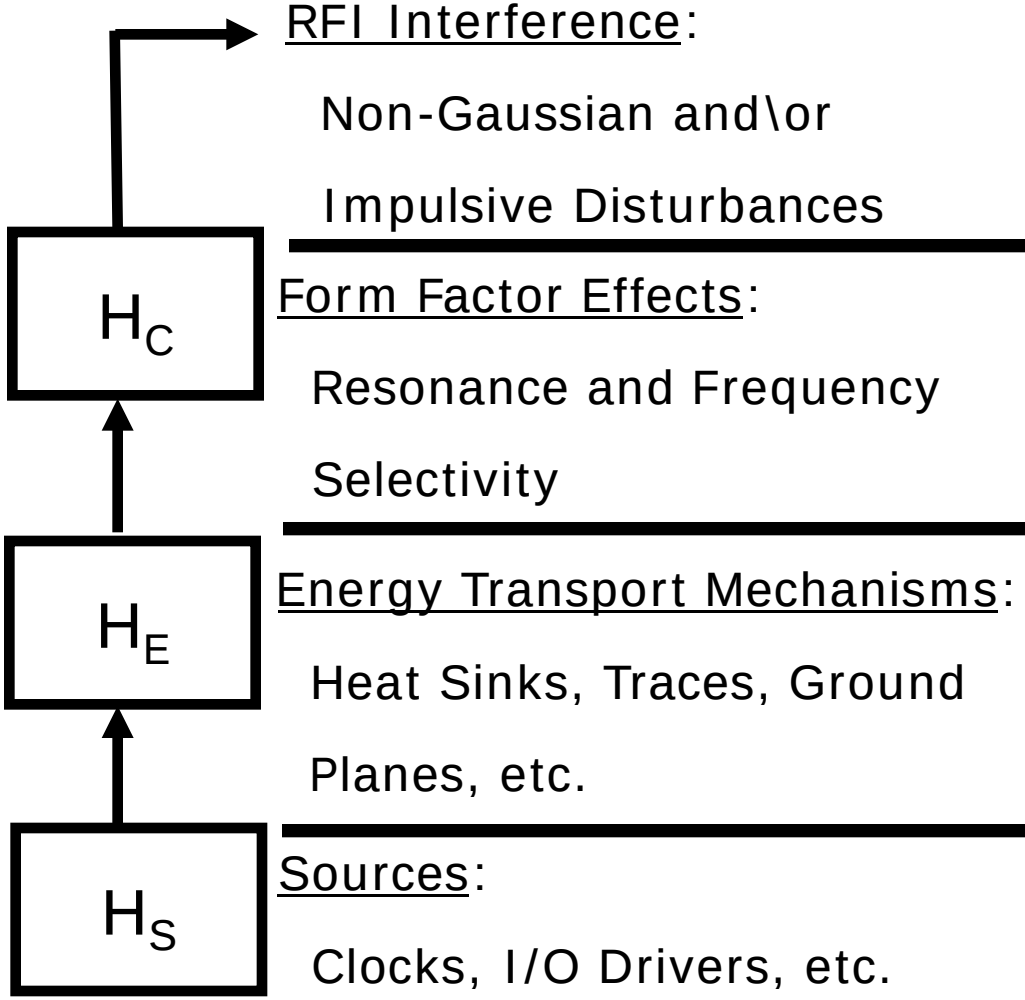


Structure of Guarding Techniques



Platform RFI: SUMMING IT UP





RFI Interference:

Non-Gaussian and\or

Impulsive Disturbances

Form Factor Effects:

Resonance and Frequency

Selectivity

Energy Transport Mechanisms:

Heat Sinks, Traces, Ground

Planes, etc.

Sources:

Clocks, I/O Drivers, etc.

RFI Workshop Summary Foil

- Platform generated RFI is a tough problem
- Significant progress has been made to understand it

- We hope you have found today useful

Thank you!