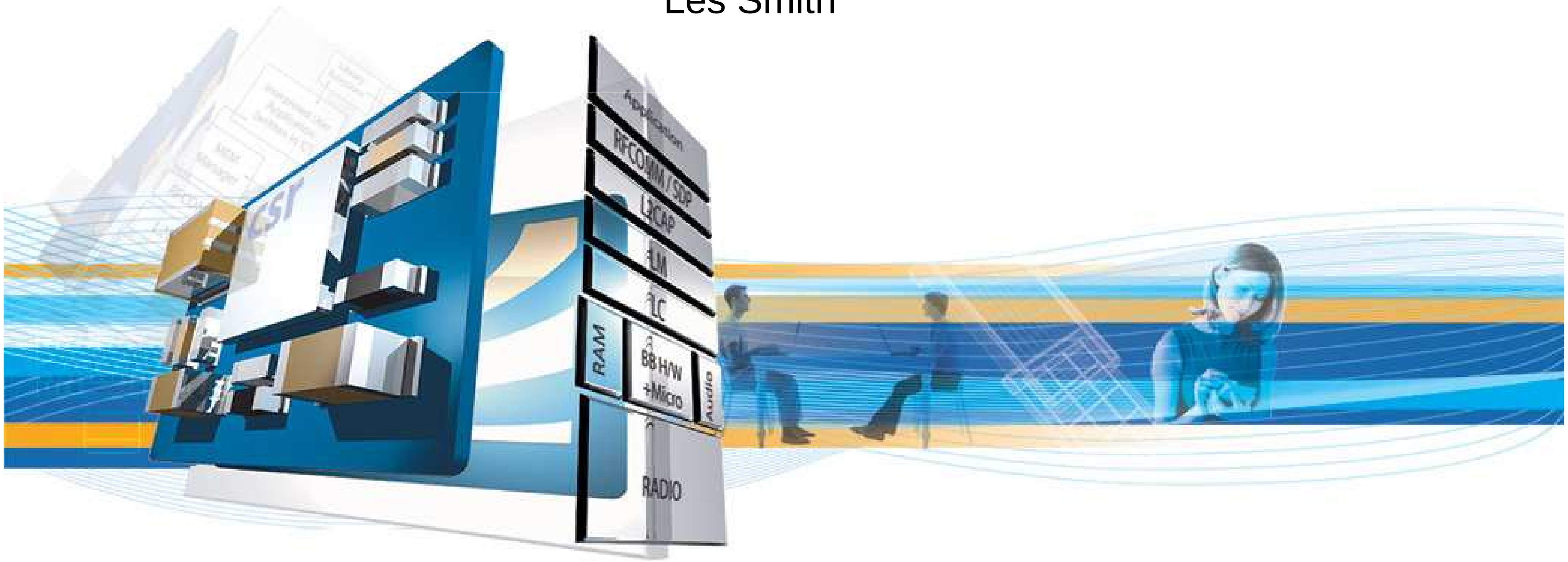
Changing the way the world connects

Review of RF Measurements for Walter

Les Smith



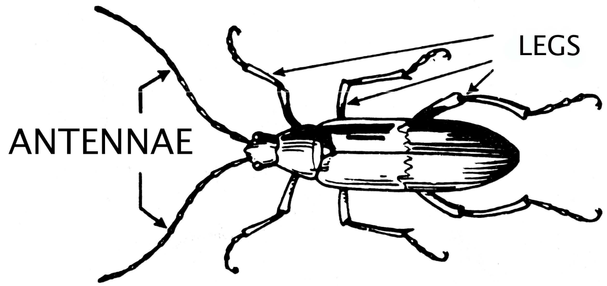
Part 1 – Document Review

Scope of Presentation

- Apologise for length of this presentation
- Review documents
  - ETSI EN302 065 V1.2.1 (2009-05)
  - Walter D4.2 V1.0 Jul 2009
  - Walter D5.3 V1.0 2009-06-30
  - Unofficial Leyio results
- Outline measurement techniques/theory
  - Measurement sensitivity
  - Tx duty cycle
- Outline measurements undertaken at CSR
  - BG1 only at this point
- Summary

Errata

- WALTER D4.2
  - Typo paragraph 3.2: 10^{-12} watts
  - Should read 10^{-15} watts
  - Version on front page wrong
  - Doc number missing (D4.2)
- ETSI Spec
  - ETSI: 2.7GHz to 3.1GHz missing (Table 3)
  - Should read 2.7 to 3.4GHz −70dBm/Hz
  - Para 5.8.2; replace ‘antenna(e)’ with ‘antenna(s)’



Walter D4.2

- States best sensitivity achieved of −60dBm/MHz
- Hence not possible to measure occupied bandwidth at −26dB (now −13dB)
- Range set to 3m
- Not possible to measure emission limits in the standard
- Measurements in report seem to be using wrong ETSI mask (maybe refers to older version)
- Measurements with cryogenically cooled LNA (20Kelvin) only covers 4 to 6GHz, hence we have no proof that it could measure down to −90dBm/MHz.

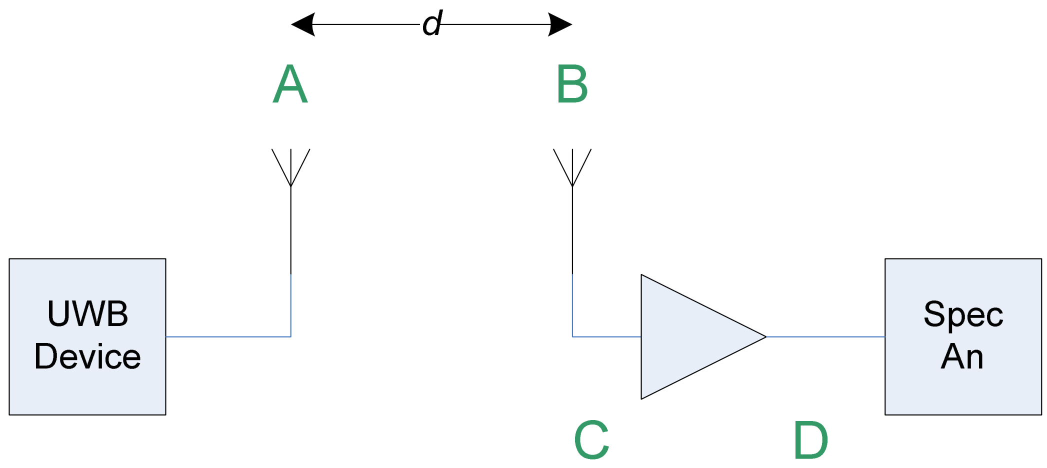
Leyio Report

- Measured using
  - Tektronix RSA 6114A spectrum analyzer
  - Agilent Infiniium DSO 8000B
- Neither has the UWB demod personality
  - No provision for inter-packet spacing
  - Or different TFC (hopping) power levels
- Helps to focus the real-world problem, that of measuring actual products

Part 2 – Noise Floor Analysis

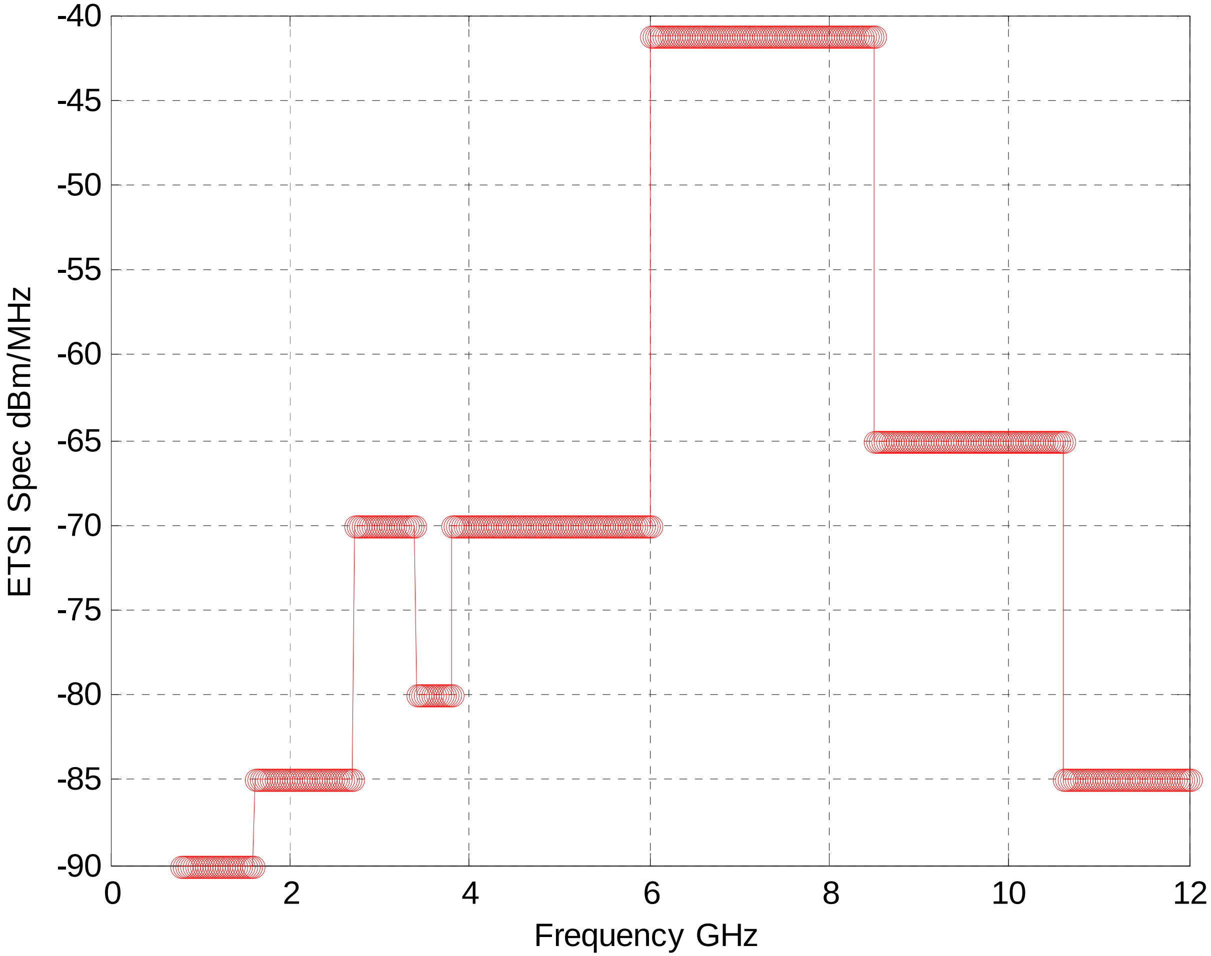
Outline Measurement Theory

- Consider a system thus:

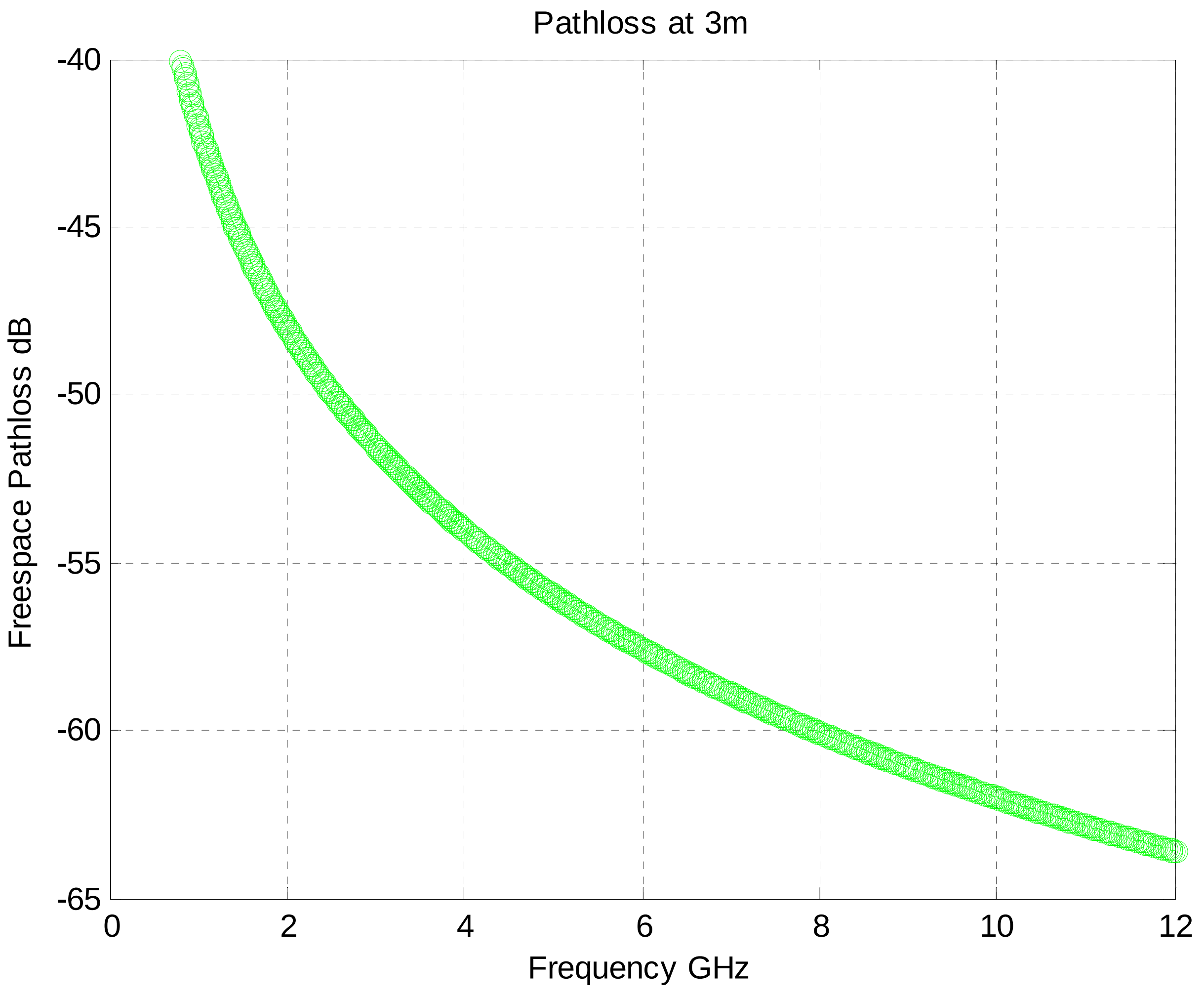


- Spec states −41.3dBm/MHz PSD at point A (EIRP)
- ETSI spec limits apply at point A
- Assume *d* is 3m

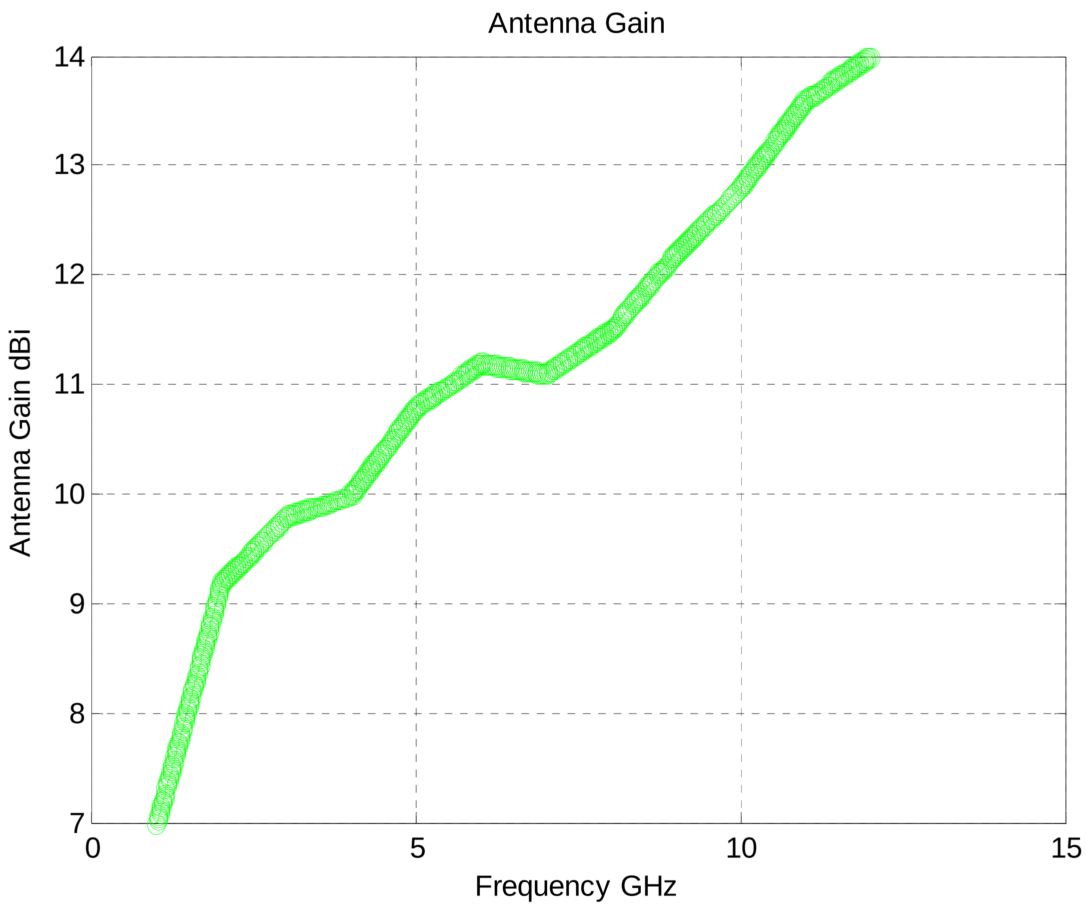
Current ETSI Spec Limits

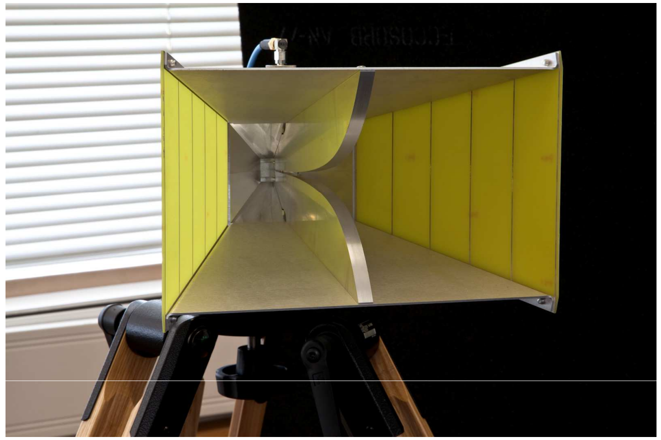


Free-space Path Loss

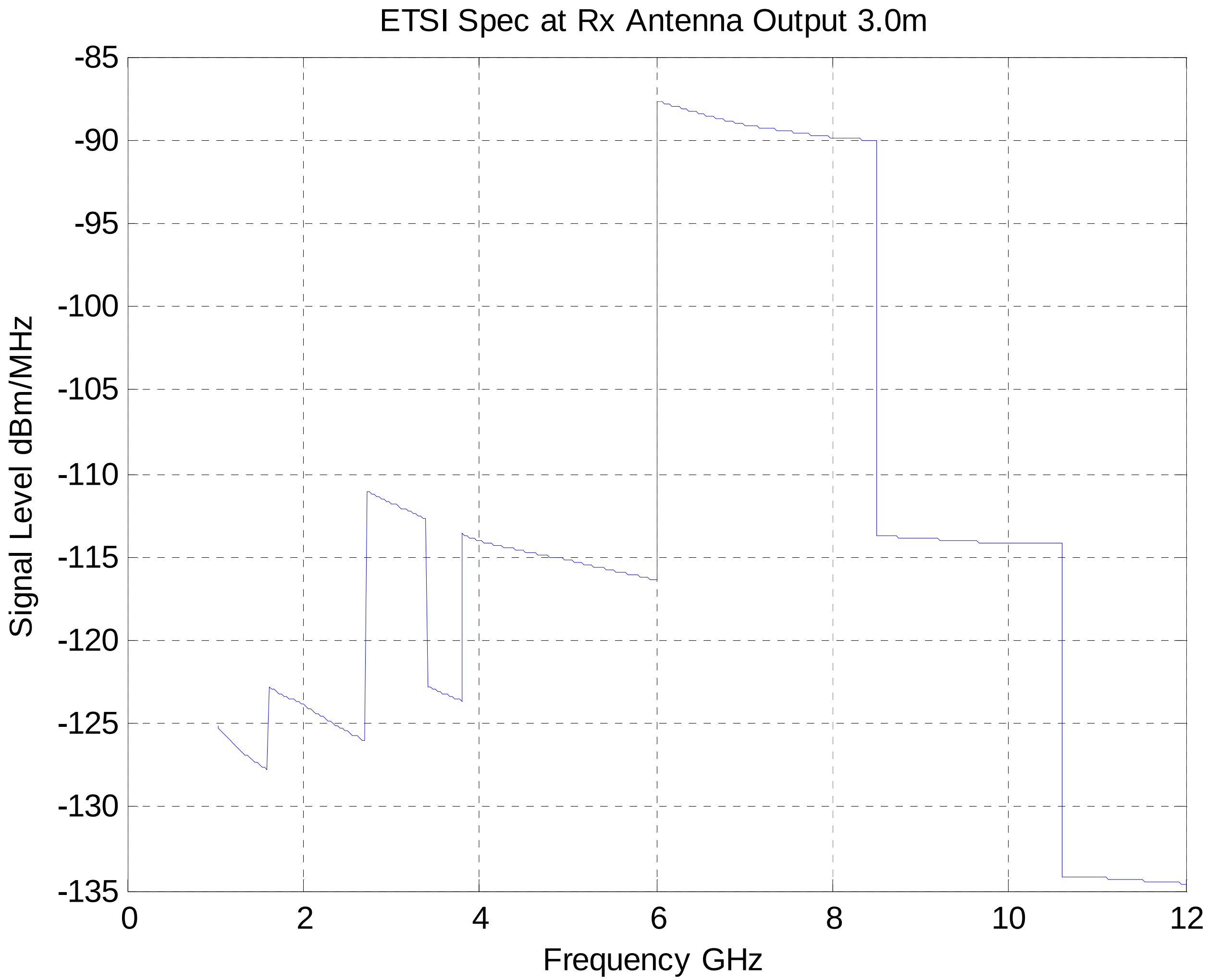


Rx Reference Antenna (1 to 18GHz)





ETSI Limits at Rx Antenna Output (Point C)

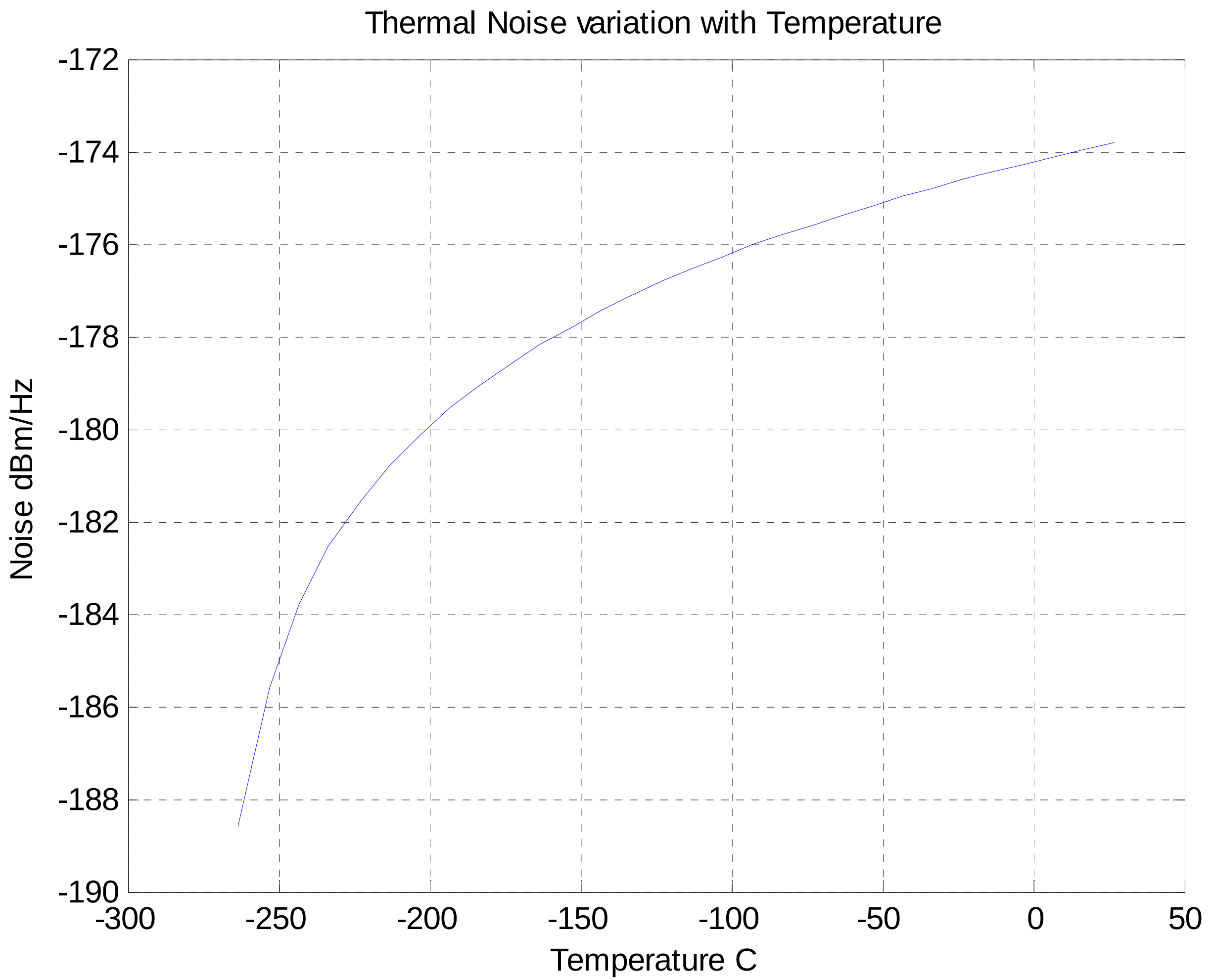


ETSI Limits at Point C (Refer to Plot Above)

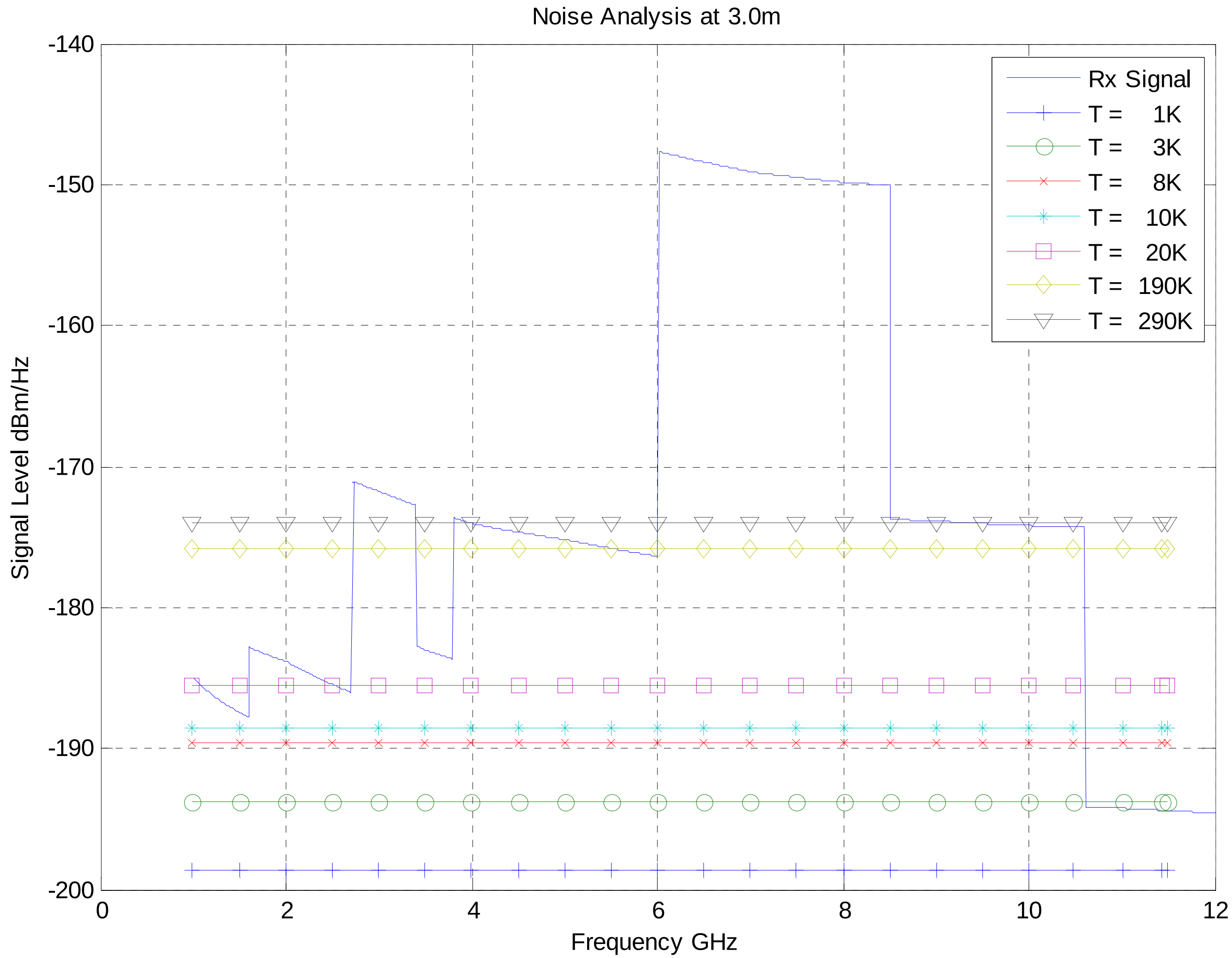
- The smaller the number, the more sensitivity we need to measure it
- Note the most difficult frequencies:
  - 1.6GHz: −128dBm/MHz
  - 2.7GHz: −126dBm/MHz
  - 3.8GHz: −124dBm/MHz
  - Frequencies above 10.6GHz

- Now: thermal noise = 30+10*log(kTB) dBm/Hz
  - T is temperature in Kelvin
  - B is bandwidth in Hz

Thermal Noise



Overlay Thermal Noise and Convert to per Hz

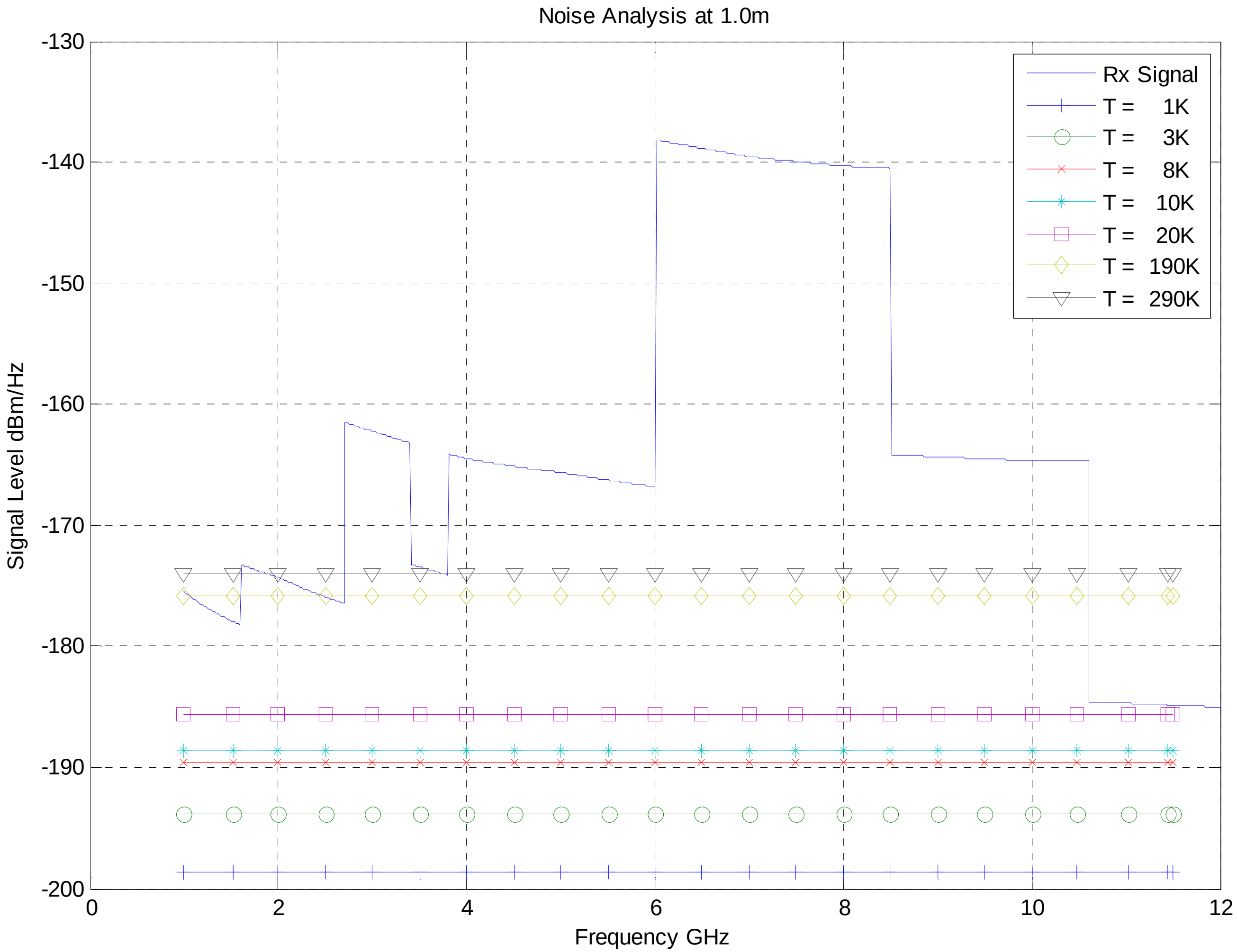


Summary 3m Range

- ETSI requires we use an LNA with a NF to give >10dB above the noise floor
- We could measure in-band signal power at room temperature
- The sensitivity required cannot be achieved even with a noiseless LNA at 1 Kelvin for emissions at 1.6GHz and above 10.6GHz

- Let’s reconsider at 1m range…

At 1m



Noise Analysis at 1.0m
Signal Level dBm/Hz
Frequency GHz
-130
-140
-150
-160
-170
-180
-190
-200
0
2
4
6
8
10
12
Rx Signal
T = 1K
T = 3K
T = 8K
T = 10K
T = 20K
T = 190K
T = 290K

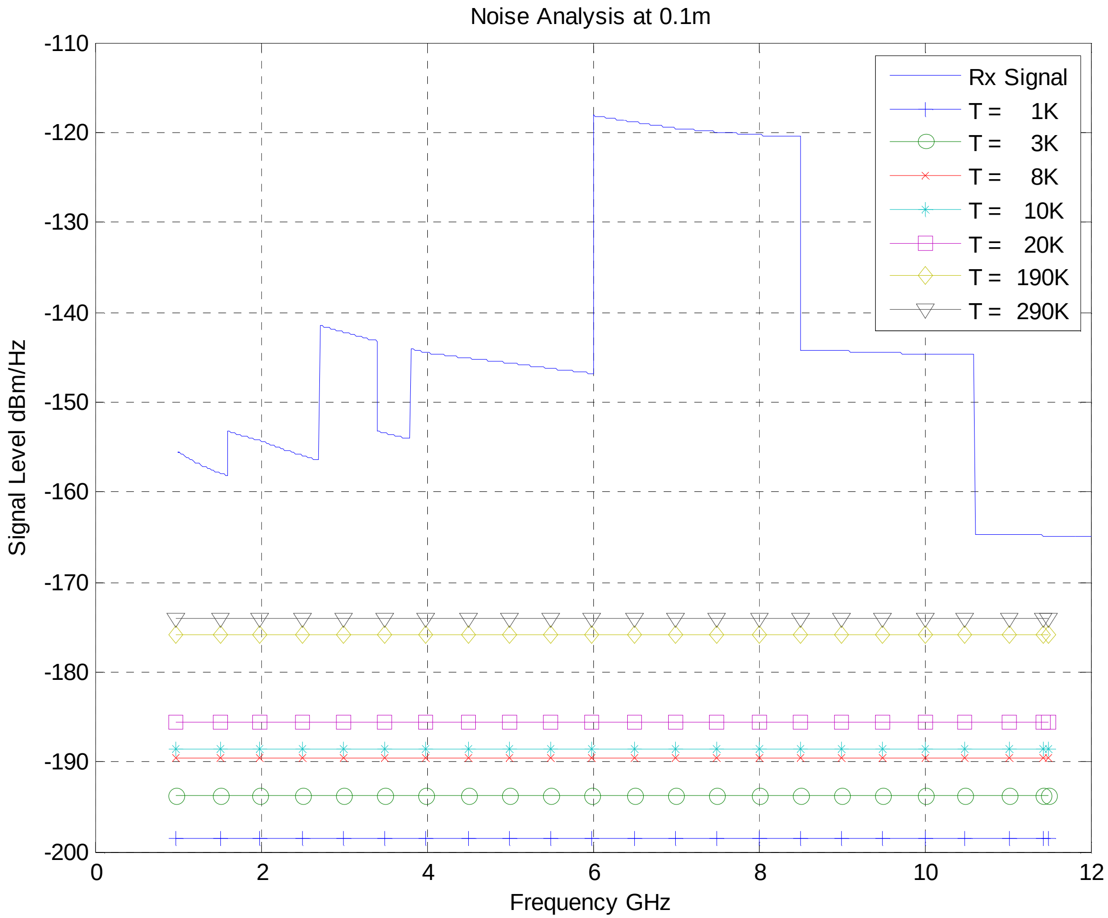
Summary 1m Range

- Emissions at 1.6GHz using an LNA with 2dB NF and a 10dB SNR margin (ETSI) will need to be cooled to <8 Kelvin
- Above 10.6GHz the sensitivity required cannot be achieved even with a noiseless LNA at 1 Kelvin

- Tests at Jodrell Bank Observatory used 20K (4GHz to 6GHz only)

Above 10.6GHz: Use *d* = 0.1m

- Antenna far-field is very short
- Can use smaller separation
- LNA will need to be cooled to <190K
- (or use higher gain antenna)?



Summary

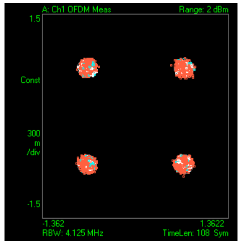
- Measurement distances should be
  - < 1.0GHz 3m
  - 1.0 to 10.6GHz 1m
  - > 10.6GHz 0.1m
- Emissions
  - LNA cooling required at 1.6GHz to 8K (not feasible)?
  - LNA cooling required >10.6GHz to 190K
- Suggest ETSI review these emission limits

Part 3 – Tx Power Analysis

UWB Signal Characteristics

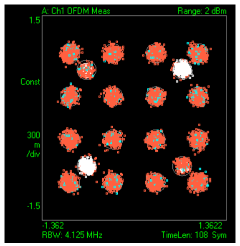
- Time Frequency Codes
  - TFC {1,2,3,4} Three band hopping
  - TFC {5,6,7} Single band
  - TFC {8,9,10} Two band hopping
- Modulation
  - QPSK:

53, 80, 106, 160, 200Mbps



  - DCM:

320, 400, 480Mbps



UWB Signal Showing Inter-Symbol Spacing

- Symbol period 312.5ns
- With fixed inter-symbol spacing allows:
  - synth time to hop to new frequency
  - PHY to use overlap-and-add to mitigate multipath

UWB Signal Showing Inter-Frame Spacing

Frame Timing

- During beaconing: one packet is transmitted every 65ms (super-frame)
  - Average power is extremely small
- During data transfer, the number of packets transmitted in a super-frame can be any number from zero to full utilisation using inter-frame spacing (SIFS) = 10µs
  - Average Tx power extremely variable
- During burst mode with minimum inter-frame spacing (MIFS) of 1.875µs
  - Average Tx power is likely to be higher
- Length of Frame is under control of the MAC
  - Average power will be variable

Question …

- Given a product such as the Leyio, how do you know
  - which TFC it will use?
  - what data-rate/modulation it will use?
  - what the packet/frame length it will use?
  - whether in burst mode?
  - data latency to read/write to flash
  - Is the unit operating in high power

- The report mentions it sending 2GB in 200 seconds, this is an averaged rate of 80Mbps, but did it use 480Mbps and use a duty cycle of 1:6? (This would save battery power)

Tx Power Requirements (1)

- Global Specs: EIRP < −41.3dBm/MHz
- Consider TFC8, 9 or 10
  - 2 band hopping (each band is notionally 528MHz)
  - Tx is on each frequency half of the time
  - So a Rx tuned to one frequency with a bandwidth of 1MHz will only ‘see’ a signal half the time
  - Hence the silicon may turn up its Tx power by 3dB and it will still meet the per 1MHz requirements
- TFCs 1-4
  - 3 band hopping
  - Tx power is increased by 4.8dB above single band

Tx Power Requirements (2)

- So if we were to measure average power
  - One band non hopping TFCs 5,6,7

    −41.3dBm + 10*log(528) + 10*log(1) = −14.1dBm
  - Two Band hopping TFCs 8,9,10

    −41.3dBm + 10*log(528) + 10*log(2)= −11.1dBm
  - Three Band hopping TFCs 1,2,3,4

    −41.3dBm + 10*log(528) + 10*log(3)= −9.3dBm
- Hence in all TFCs
  - Tx power is still −41.3dBm per 1MHz

Part 4 – Conducted Measurements at CSR

Equipment Used for Measurements at CSR

- Room temperature, range 1m
- LNA 1.8dB noise figure, gain 35dB
- Reference Rx antenna R&S HF906
- UWB device on a Lab Dev board
  - With SMA connector for conducted
  - And fitted with antenna for radiated
- Controlled by PC application – UltraTest
- Agilent low noise spectrum analyser MXA N9020A
- Agilent DSO91304A with UWB VSA
- Anritsu ML2495A Power Meter

Measurements – Conducted

- Dev board connected directly to test equipment via SMA cable
  - Cable loss not accounted for in measurements
  - Screen shots give actual reading, no corrections applied
- Oscilloscope (VSA) setup i.a.w. Wi-Media
- Spectrum Analyser (SA) setup i.a.w. ETSI
  - Plus setting display to average
- UltraTest used to set the signal properties

- By choosing different payload lengths at each data-rate, a fixed frame length can be achieved…

Force 96 Symbol Frames

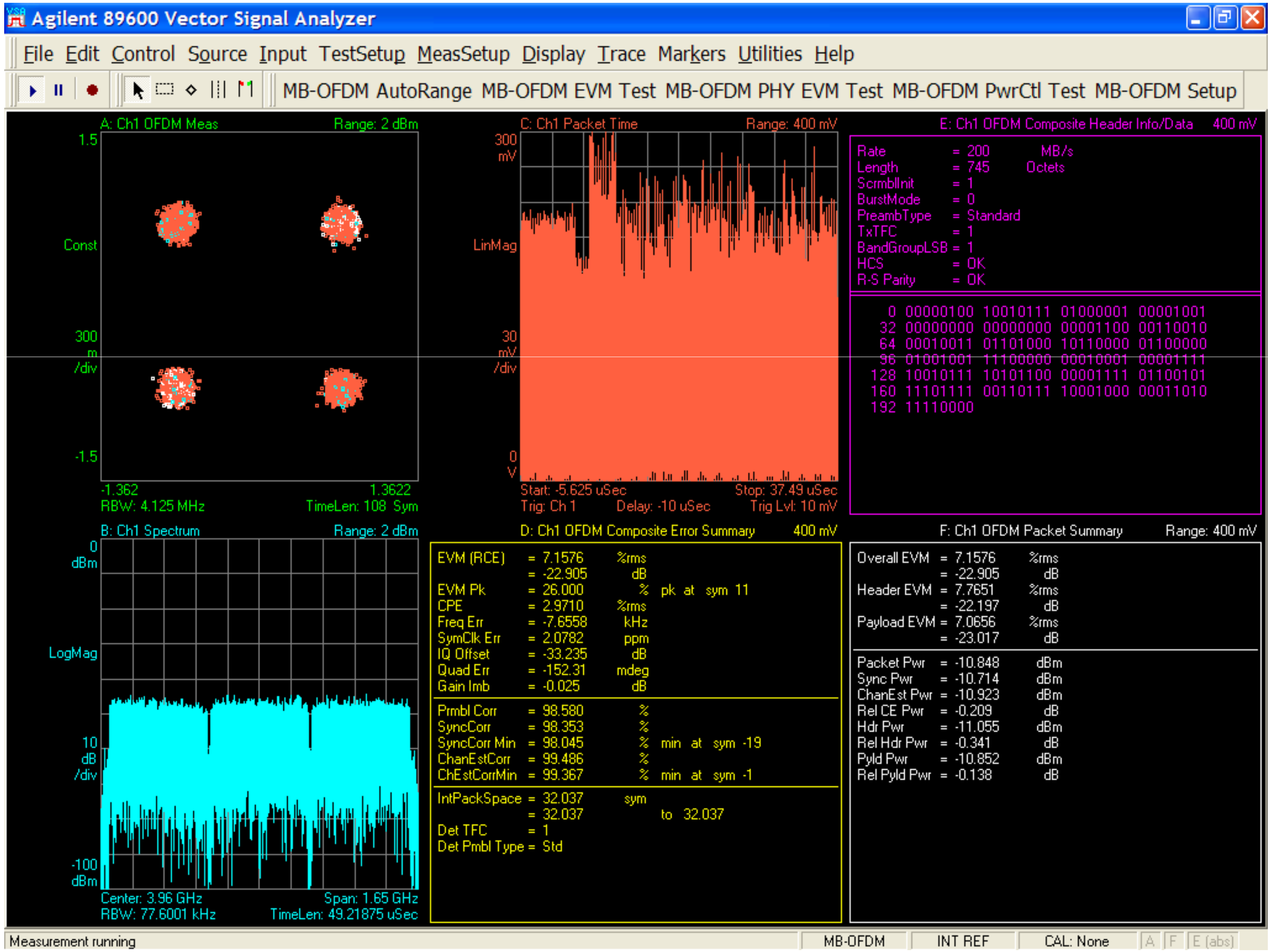
Data Rate Mbps	Payload Length Octets	Frame Length	Spacing
53	195	43μs	10μs
80	295	43μs	10μs
106	395	43μs	10μs
160	595	43μs	10μs
200	745	43μs	10μs
320	1195	43μs	10μs
400	1495	43μs	10μs
480	1795	43μs	10μs

Test Results, BG1 TFC1, continuous Tx

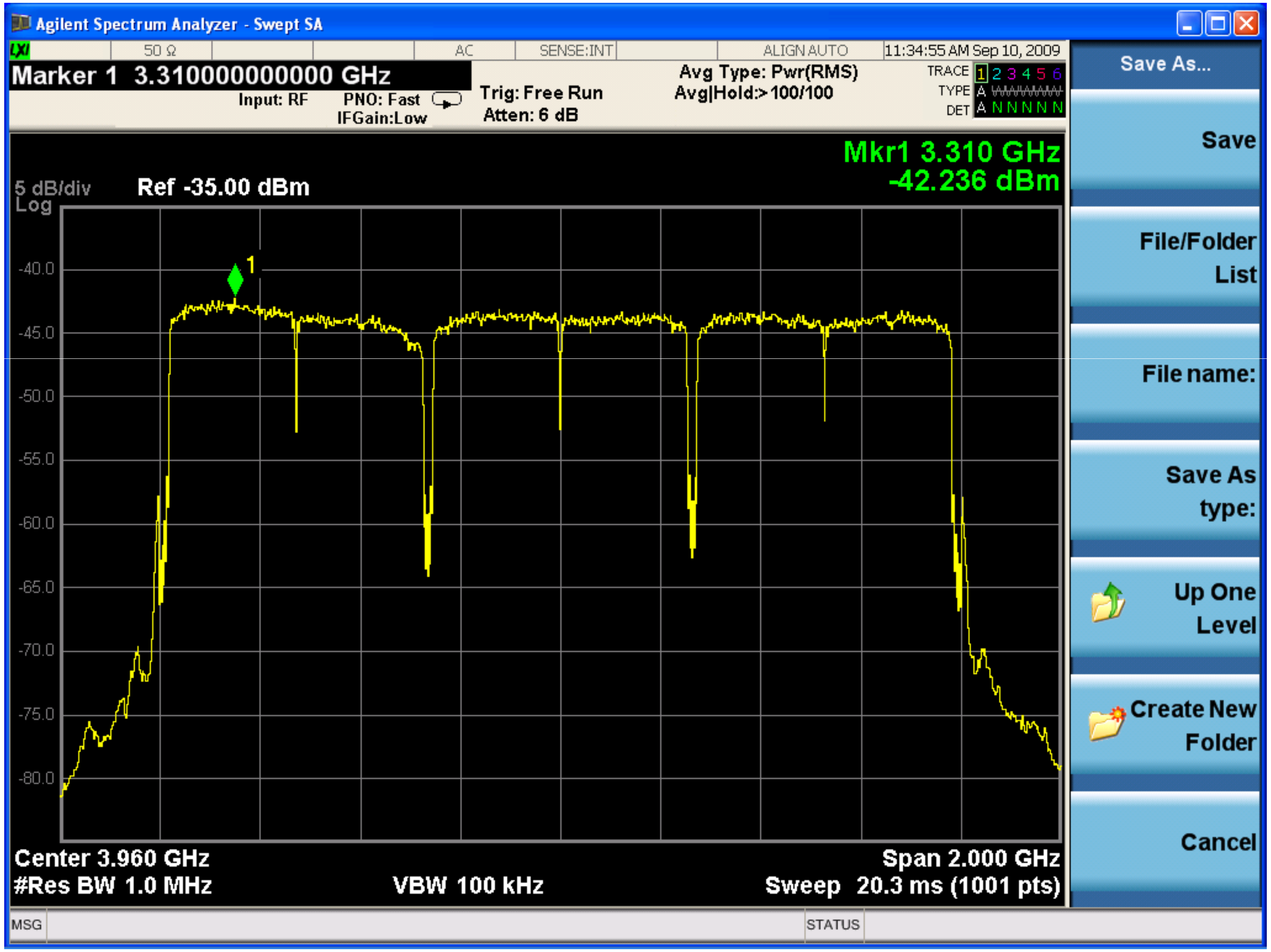
Signal	Frame Length	Frame Spacing	Pwr Mtr dBm	VSA dBm	Spec.An dBm/MHz
53Mbps	43µs	10µs	−12.0	−11.0	−42.3
200Mbps	43µs	10µs	−11.8	−10.8	−42.0
480Mbps	43µs	10µs	−12.0	−10.9	−42.4
53Mbps Burst	43µs	1.875µs	−11.2	−10.9	−41.7
200Mbps Burst	43µs	1.875µs	−11.1	−10.9	−41.5
480Mbps Burst	43µs	1.875µs	−11.3	−11.0	−41.8

- Tx duty cycle
  - normal frames 81.1% (0.908dB)
  - burst frames 95.8% (0.185dB)

VSA Screenshot TFC1



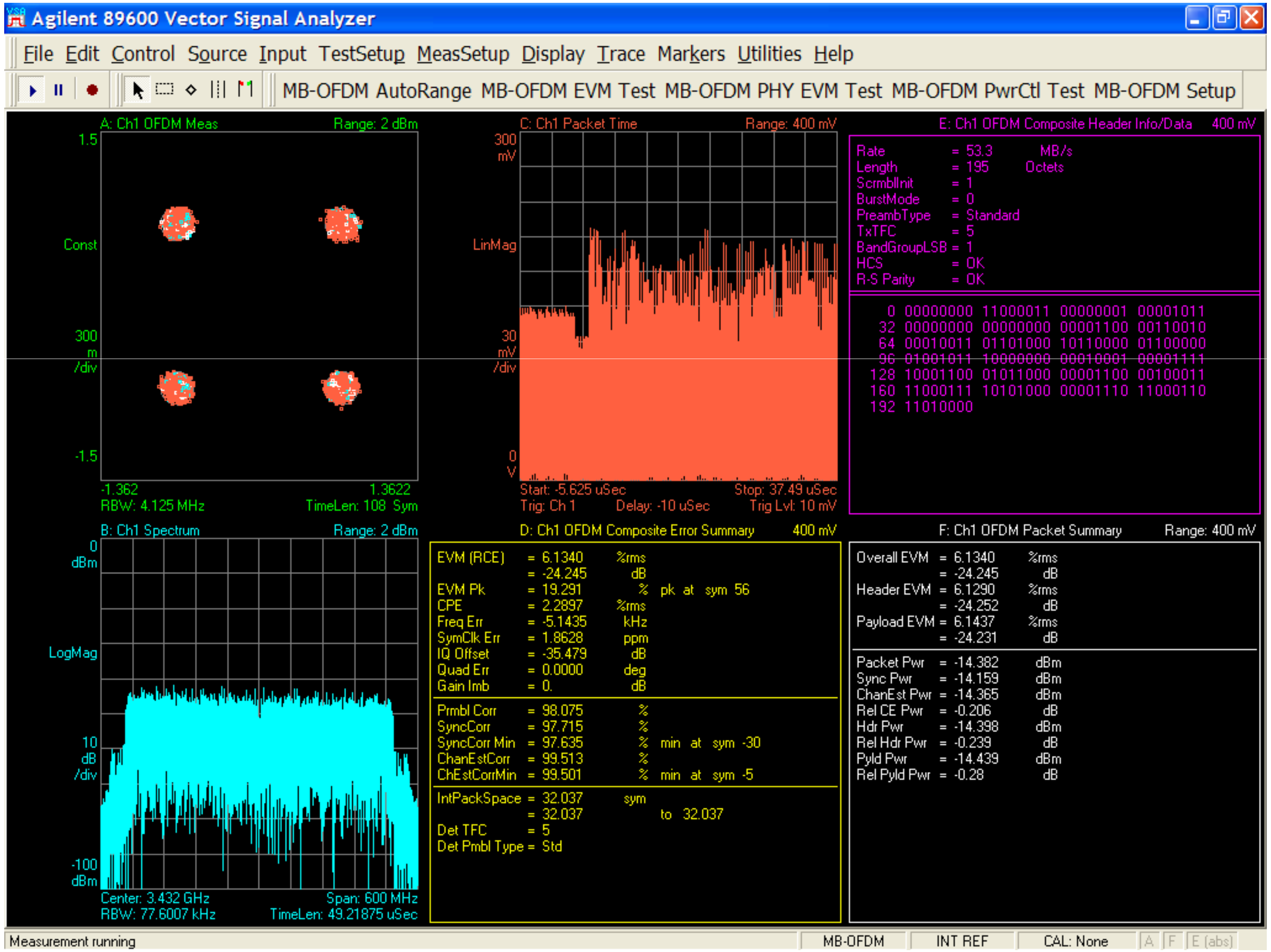
Spectrum Analyser Screenshot TFC1



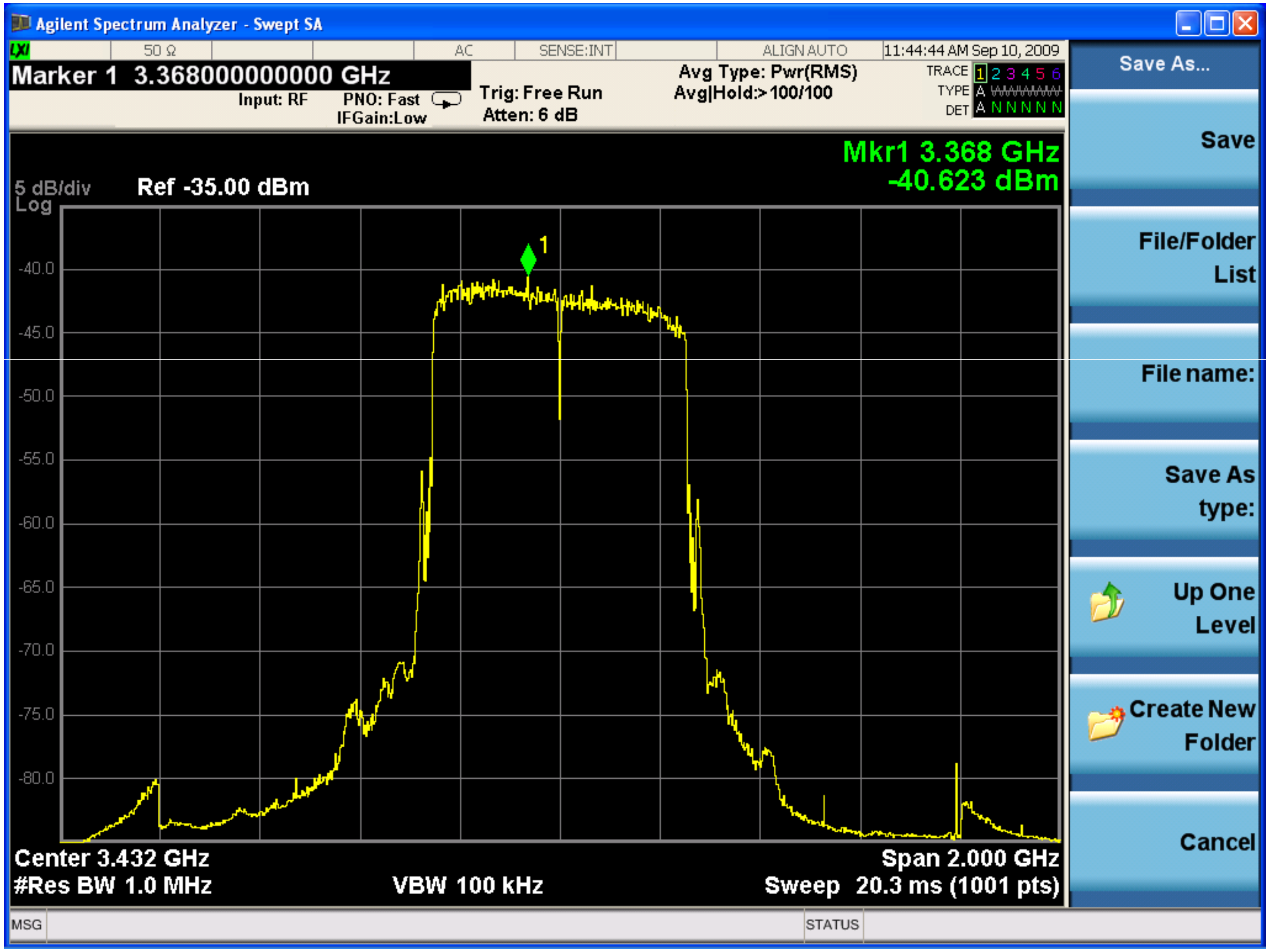
Test Results, BG1 TFC5, continuous Tx

Signal	Frame Length	Frame Spacing	Pwr Mtr dBm	VSA dBm	Spec.An dBm/MHz
53Mbps	43µs	10µs	−15.5	−14.4	−40.7
200Mbps	43µs	10µs	−15.5	−14.4	−40.6
480Mbps	43µs	10µs	−15.6	−14.5	−40.8
53Mbps Burst	43µs	1.875µs	−14.8	−14.4	−40.0
200Mbps Burst	43µs	1.875µs	−14.8	−14.5	−40.2
480Mbps Burst	43µs	1.875µs	−14.9	−14.6	−40.4

VSA Screenshot TFC5



Spectrum Analyser Screenshot TFC5



Contrast VSA and Power Meter Results (53Mbps)

Mode	TFC	TFC1	TFC5
Normal	Power Meter Reading	−12.0	−15.5
	Corrected for Duty Cycle (+0.908dB)	−11.1	−14.6
	VSA reading	−11.0	−14.4
	Error	+0.1	+0.2
Burst	Power Meter Reading	−11.2	−14.8
	Corrected for Duty Cycle (+0.185dB)	−11.0	−14.6
	VSA reading	−10.9	−14.4
	Error	+0.1	+0.2

Analysis

- On each of the three equipments:
  - Power is data-rate invariant
  - (for a fixed frame/packet length)
- Power Meter
  - Burst mode powers are ~0.72dB higher
  - Accounted for in difference in duty cycles
- VSA
  - Reports the same power in normal and burst mode
  - Because it’s reporting the power during the packet

Test Results: BG1, 53Mbps, Normal Packets

TFC	№ Hop Bands	Power Meter Corr for Duty Cycle dBm	VSA dBm	Spec.An dBm/MHz
1	3	−12.0 + 0.91 = −11.1	−11.0	−42.3
8	2	−13.9 + 0.91 = −13.0	−13.0	−42.6
5	1	−15.5 + 0.91 = −14.6	−14.4	−40.7

Signal	№ Hop Bands	Req. power Increase dB	VSA dB	Actual error from UWB Tx	Spec.An dB
TFC1 w.r.t. TFC5	3	+4.8	+3.4	−1.4	−1.6
TFC8 w.r.t. TFC5	2	+3.0	+1.4	−1.6	−1.9
TFC5 w.r.t. TFC5	1	0	0	0	0

Variation of Tx Power with TFCs

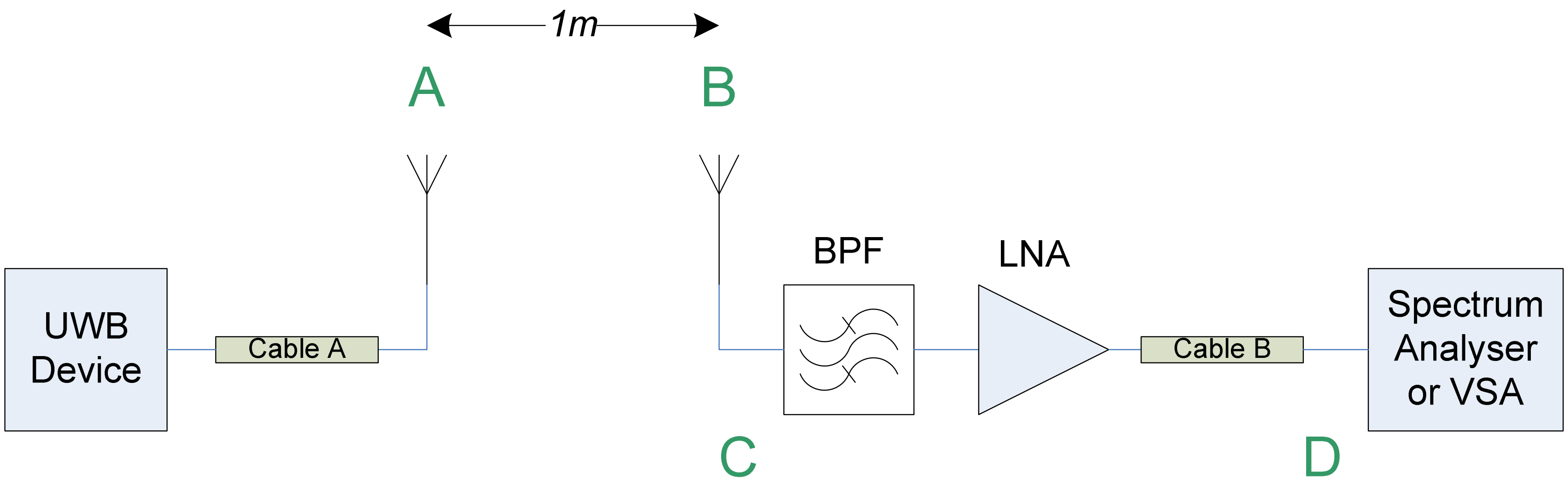
- The VSA is reporting power correctly
  - 2-band hopping is light in power by 1.6dB
  - And 3-band hopping by 1.4dB
  - This UWB Tx could be calibrated better
  - The absolute power of this Tx is a little low, some maybe accounted for in the cable
- The Spectrum Analyser is reporting correctly
  - The difference in power levels in a per MHz bandwidth
  - But the absolute levels would need to be corrected by the Tx duty cycle.

Summary Conducted Measurements

- Power levels are not dependant on data-rate or modulation type
- Power levels are grossly affected by frame/packet length
- Power levels are affected by inter-packet gap, SIFS/MIFS normal/burst mode
- Average power levels are dependant upon TFC
- ETSI does not take these into account
  - Needs to add a mark/space correction statement
- UWB standards need to add a test-mode
  - To ensure a particular packet length and Tx in full power

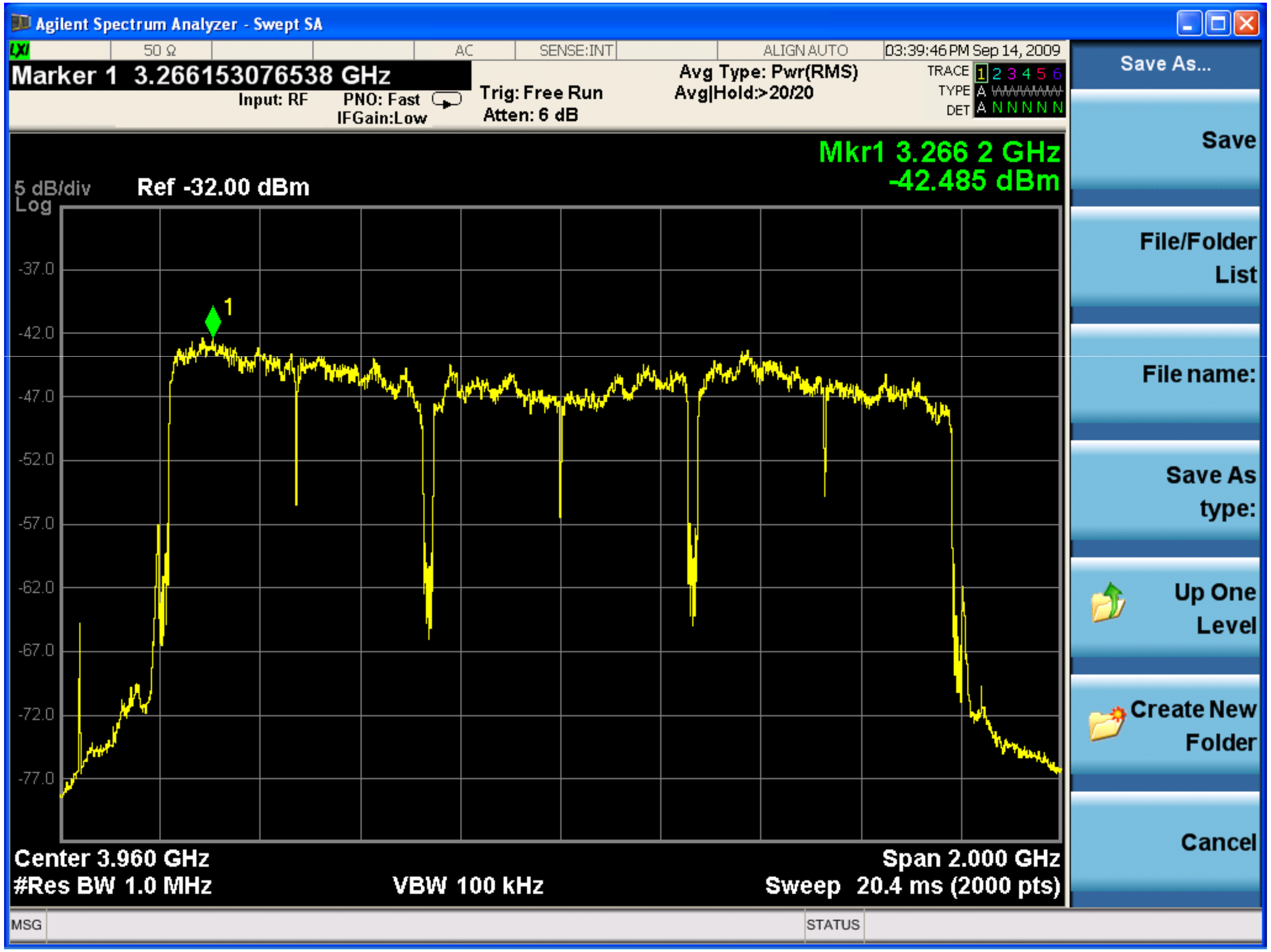
Part 5 – Radiated Measurements at CSR

Radiated Measurement Setup



- Path Loss = 32.45 + 20 * log(*f*)
- Cable B Loss = 2.1066 * log(*f*) − 0.2351dB (*f* in GHz)
- Rx Antenna Gain = 11.3dB (3.1GHz to 4.8GHz)
- BPF Loss 1.5dB
- LNA Gain 35.5dB

Spectrum Analyser Screenshot (TFC1)



Calculation of actual EIRP (TFC1)

Element	Correction Applied	Result
Reading (at 3.2GHz in this case)		−42.5dBm/MHz
Duty Cycle (96symbol frame SIFS)	+0.91dB	
Cable-B Loss	+0.83dB	
LNA Gain	−35.5dB	
BPF Loss	+1.5dB	
Ref Antenna Gain (at 3.2GHz)	−9.8dB	
Path Loss (1metre at 3.2Hz)	+42.6dB	
Total Correction		+0.54dB
EIRP (Global specs −41.3dBm/MHz)		−42.0dBm/MHz

Spectrum Analyser Screenshot (TFC5)

Calculation of actual EIRP (TFC5)

Element	Correction Applied	Result
Reading (at 3.2GHz in this case)		−40.5dBm/MHz
Duty Cycle (96symbol frame SIFS)	+0.91dB	
Cable-B Loss	+0.83dB	
LNA Gain	−35.5dB	
BPF Loss	+1.5dB	
Ref Antenna Gain (at 3.2GHz)	−9.8dB	
Path Loss (1metre at 3.2Hz)	+42.6dB	
Total Correction		+0.54dB
EIRP (Global specs −41.3dBm/MHz)		−40.0dBm/MHz

Calibration

- In order to minimise measurement uncertainties
  - Any cables must be calibrated over the frequency range
  - Take account of path loss variation over the bandgroup
    - Path loss delta across TFC1 is
    - 20*log(4.8/3.1) = 3.8dB
  - Frequency response of LNA
  - Frequency response of Test Antenna

Maximum Peak Radiated Power

- To do …

- Bandwidth of 8MHz possible not 50MHz
- Spec limit changed from 0dBm/50MHz to −8dBm/8MHz

Rx Spur

- To do …

Tx Power Control

- To do …

Emissions

- Noise floor good enough to do …
  - TBD
- But not
  - 1.6GHz
  - TBD

Changing the way the world connects