Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Coexistence-of-UWB-and-Mobile-Phones]
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Re: [UWB interference to mobile phones]

Abstract: [Recent measurements of wide-band signals in the 1.8-2 GHz mobile phone bands shows that UWB signals at FCC limit levels and distances as close as 1 m from a mobile phone can be detected by the mobile phone, but cause no harmful interference.]

Purpose: [This document provides P802.15 with recent information regarding interference measurements to mobile phones in the 1.8-2 GHz range. The data are relevant to ITU-R TG1/8 deliberations as well as to pending regulatory activities around the world, and thus affect the development of standards involving UWB.]

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Coexistence of UWB and Mobile Phones

16 September 2005

Kai Siwiak and Gregg Rasor

We Measured Mobile Phones in Three Situations to Establish Coexistence ...

1. Conducted signal to a Mobile Phones (MPs) inside a shielded box
2. Radiated signal to MPs mounted on 'phantom human heads'
3. Radiated signal to MPs mounted on 'phantom human heads' with
   - FCC limit level UWB signal at 3 m
   - FCC limit level UWB signal at 1 m

We Used the Pristine Environment of a Shielded Anechoic Chamber

- Tests were carried out at Florida Atlantic University, Boca Raton, FL
  - FCC certified EMI chamber
  - Fully Shielded and Anechoic (with floor absorber)
- The critical MP link is the cell site base to the MP, see [Fisher2005] and [Fisher2005a]
- We developed novel measurement procedures
- We measured BER / FER / BLER and “call originate sensitivity” (COS) in:
  - Conducted measurement configuration
  - Radiated configuration

We Discovered

- In the pristine conditions of a shielded, anechoic and static environment
- At the peak of the MP antenna pattern, UWB at 3 m distance is nearly imperceptible
- UWB at 1 m distance is imperceptible at the field strengths needed to provide *the most marginal cell system coverage*

Our Radiated Testing Configuration

- We used a common antenna to radiate both the cell phone signal and the UWB signal because *MP antenna patterns are not omnidirectional*
- The Wireless Test Set (WTS) was used in a novel radiating mode as a “base station cell site”
- RF components (couplers) were used in novel ways to isolate and/or combine signals
- We carefully calibrated all the signal paths

Calibrated Radiated Signal Test Configuration

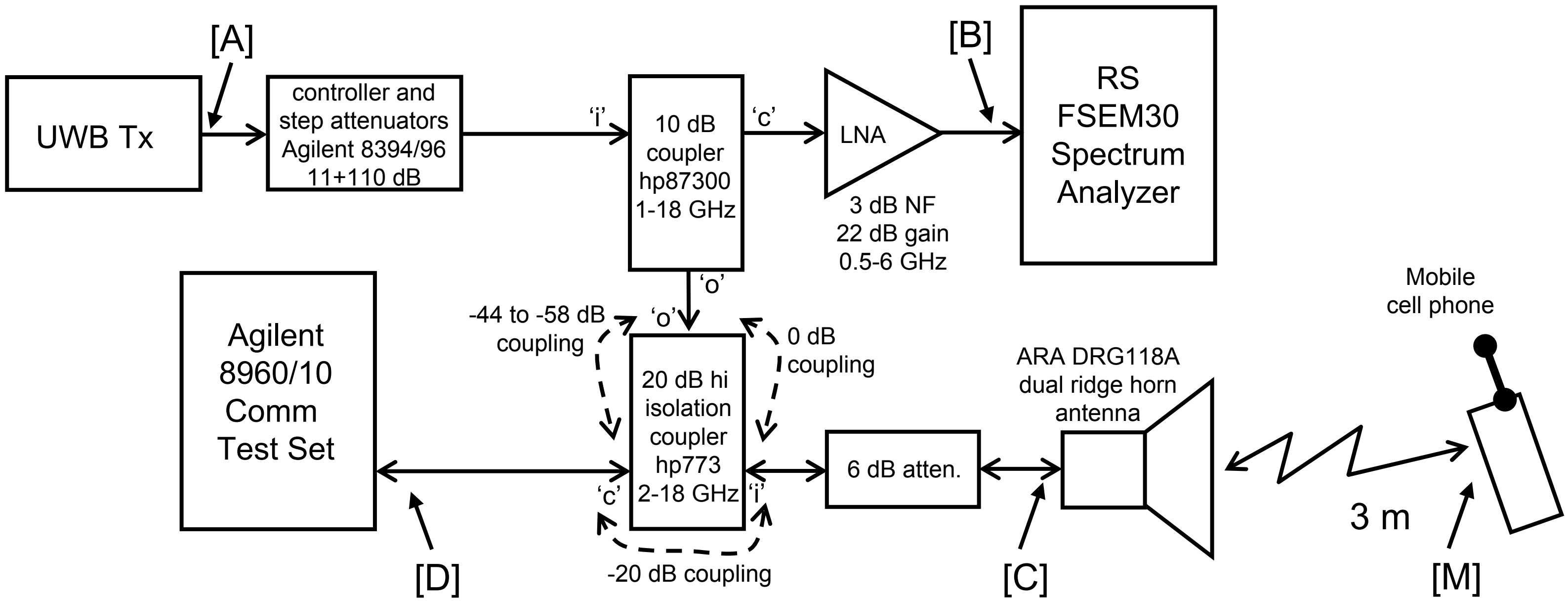


Figure 1 – Test configuration "A" using a single test antenna

Measurement Setup “A”

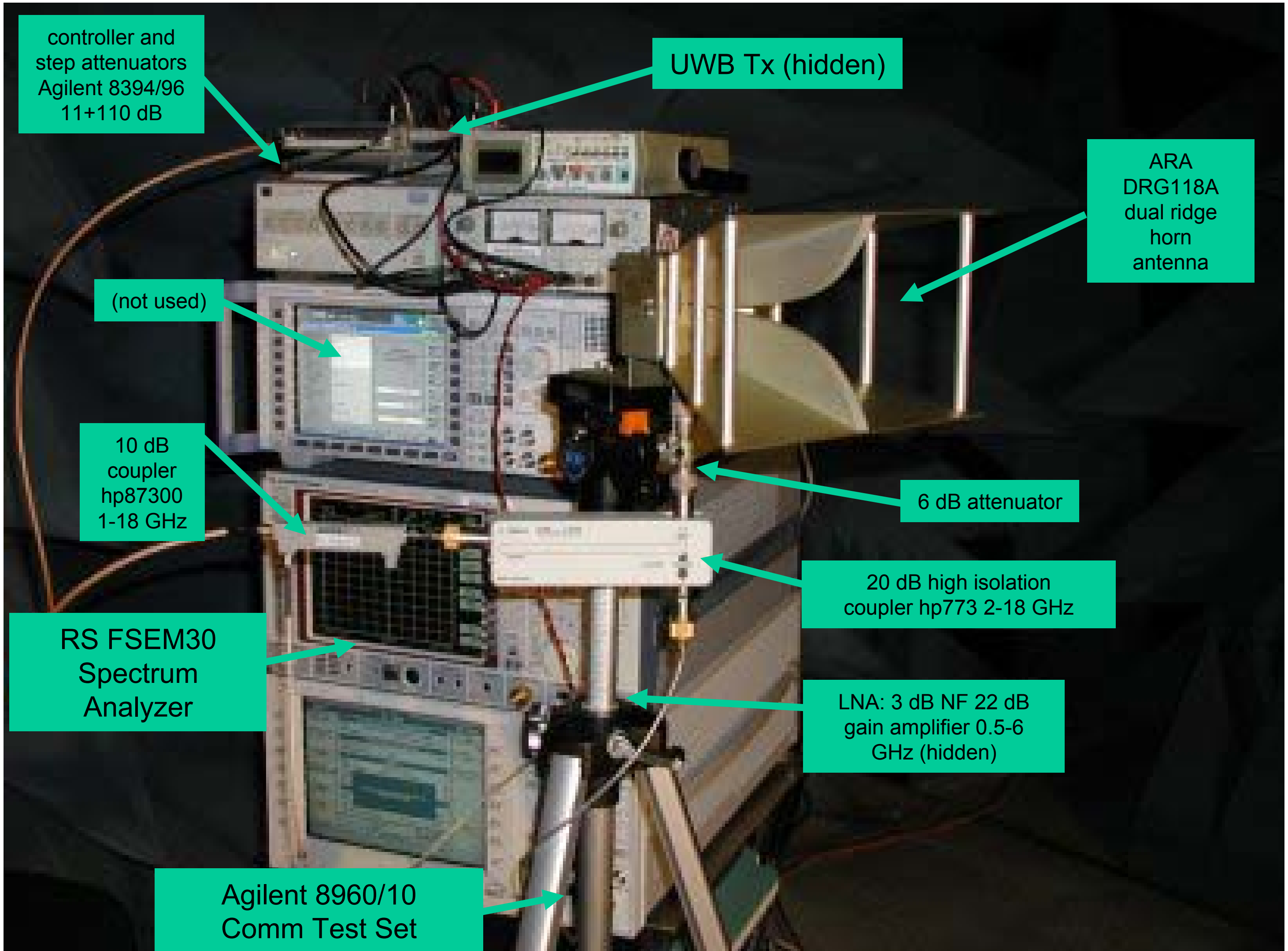


Figure 2a – Test configuration uses a single ARA DRG118A test antenna for the cell signal and the UWB signal

Human Head Phantom Fixture

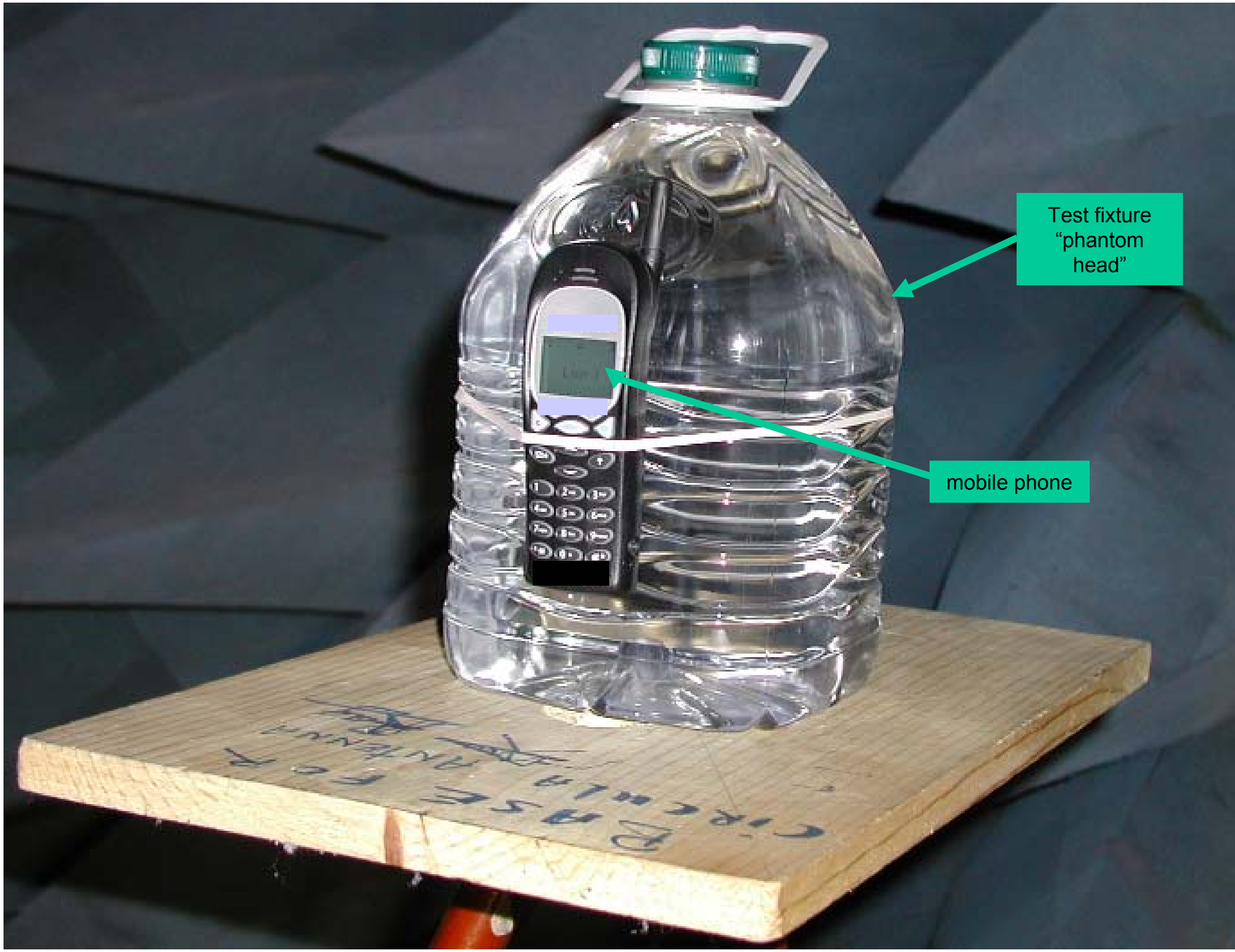


Figure 2b – Mobile phone mounted on the water filled test fixture, see [Siwiak1998].

3 m Test Range

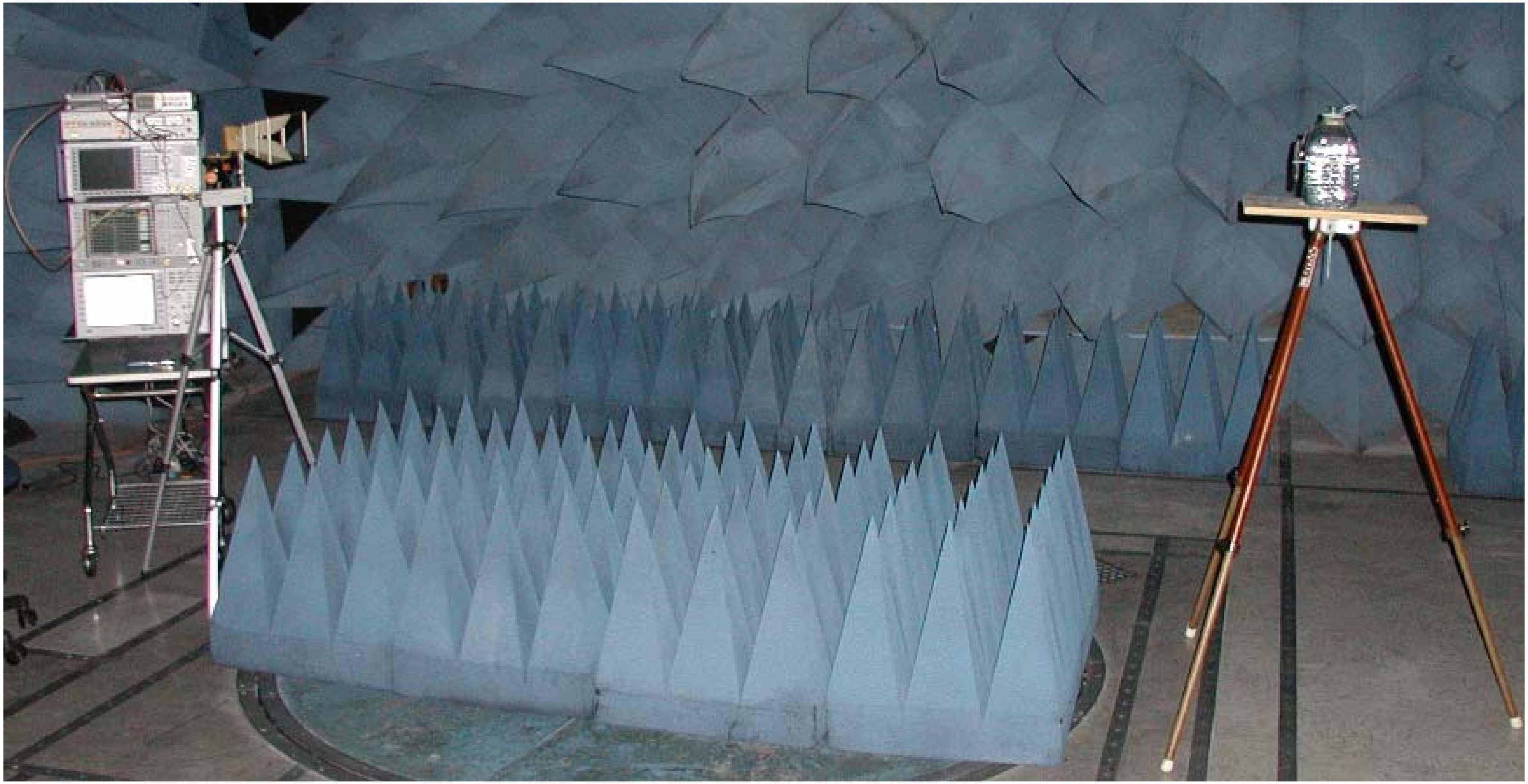


Figure 2c – Free space test configuration in the shielded FAU EMI anechoic chamber.

Profile View of 3 m Test Site

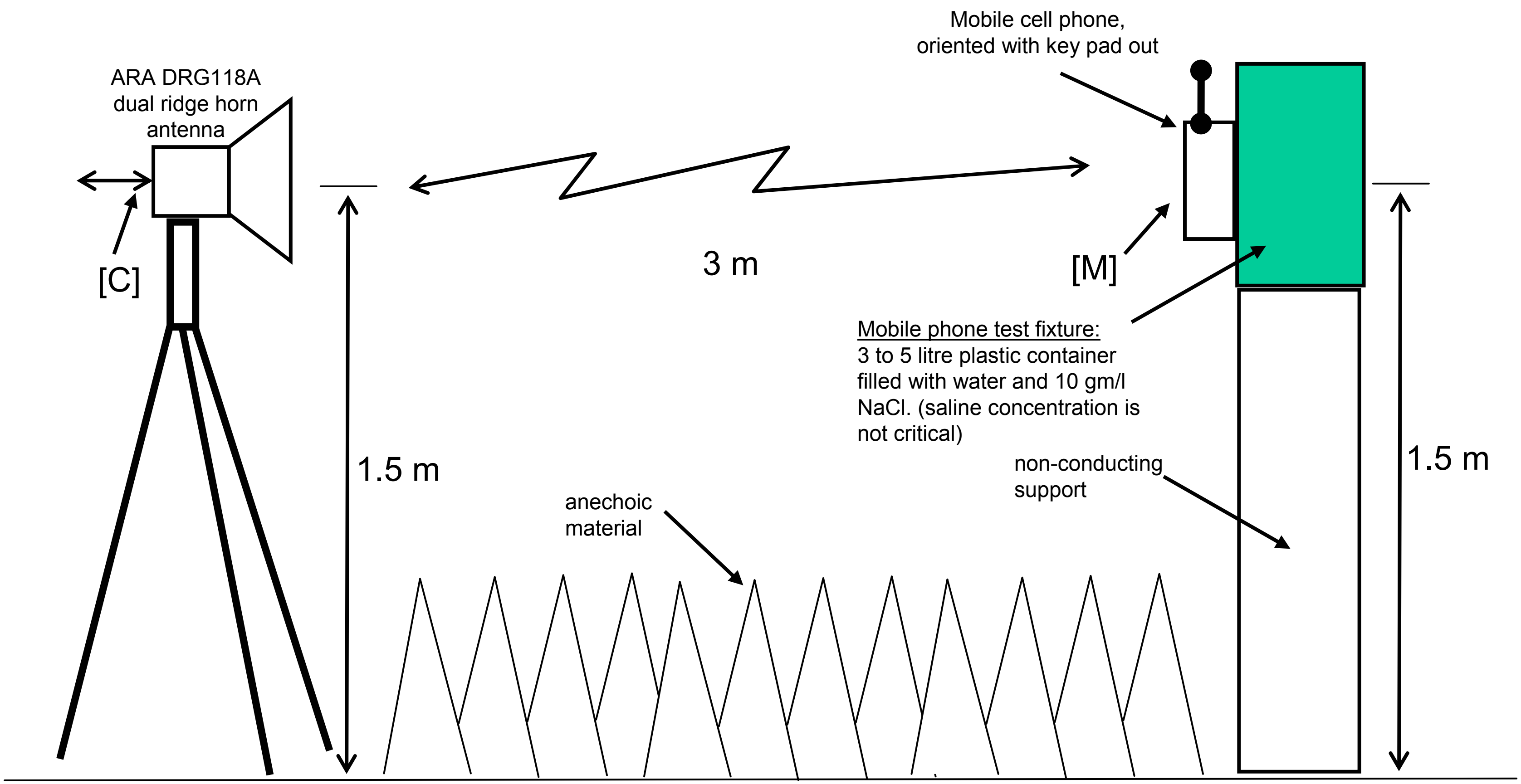


Figure 3 – Profile view of 3 m test site

We Measured MP Receiver COS:

a novel way of finding radiated receiver sensitivity

- Call Originate Sensitivity (COS) is the signal level, referenced to power received by a 0 dBi antenna, which results in at least 3 successful received calls in a row
- COS is the 80% calling probability, it is the 50% probability of three successful calls in a row:

$$P^3 = 0.5, \text{ so } P=0.5^{1/3} = 0.8$$

- Method similar to selective call paging sensitivity [Siwiak 1998], except here a strong signal is first sent to ‘sync-up’ the MP
- We found that the COS corresponds roughly to the 8-10% FER or 10-15% BER in static pristine environment
- The 80% COS is an extremely fragile operating point, but relatively easy to measure
- We found that 7 dB more signal is needed for usable MP operation

Conducted Signal Tests

- Conducted signal tests and error ratio tests are performed with the MP inside a shielded enclosure, see Figure 5
- Equipment configuration is similar to Figure 1, but with transmitting horn antenna replaced by shielded test enclosure

Conducted Signal Test Configuration

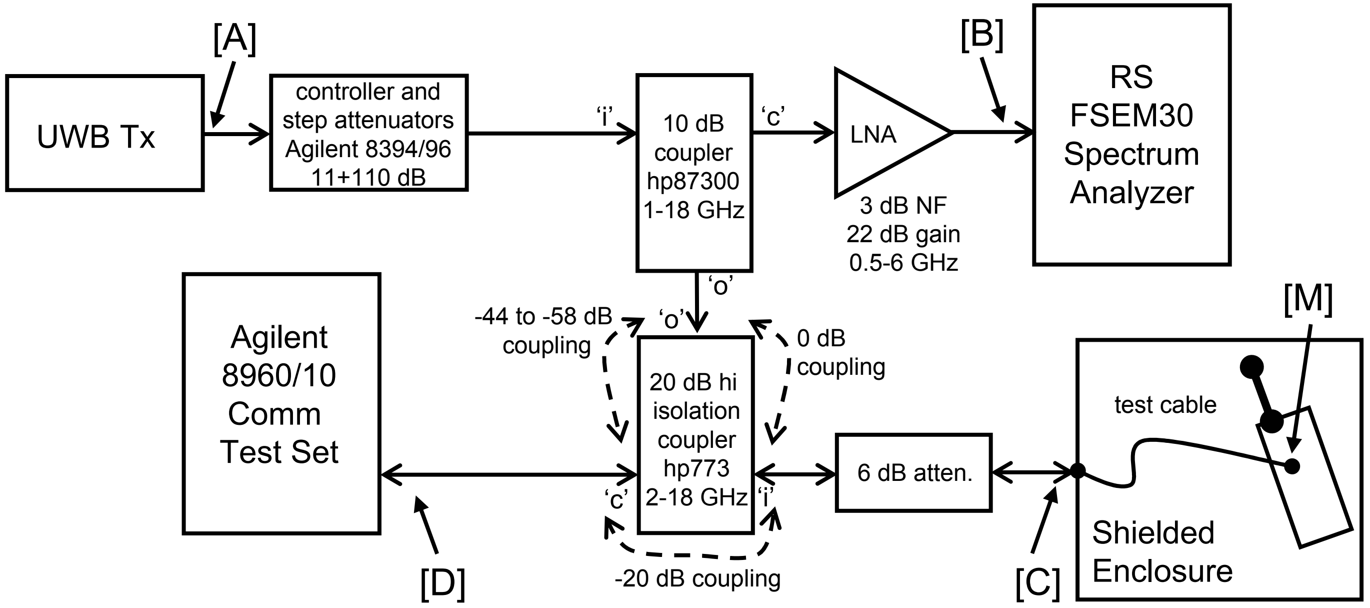


Figure 5 – Test configuration for conducted sensitivity and error ratio tests

Conducted COS Measurements

UWB Tx is off, equipment configuration Figure 5

1. MP received power level is measured at MP 50 ohm test port
2. Synchronize MP at high signal level, -80 dBm
3. Step Wireless Test Set transmit level down in 2 dB increments, send COS to obtain at least three successes in a row
4. Record the failed signal level = FS
5. Re-synchronize the MP with COS = -80 dBm
6. Starting at FS+2dB, obtain 3 calls in a row
7. Reduce COS in 1 dB increments while obtaining 3 calls in a row
8. Record the last occurrence, lowest signal level obtained for three successful calls in a row as FS dBm
9. The conducted sensitivity is FS dBm

How We Measured Conducted Error Ratios

Set UWB Tx off, equipment configuration Figure 5

1. Set the Wireless Test Set to measure error ratios
2. Synchronize the MP with COS = -80 dBm
3. Record error ratios (BER, FER, and BLER as appropriate) vs. signal level every decibel for error ratios between 10^{-4} and call failure point
4. Recorded BER on all GSM phones, plus FER (GSM) and BLER (wcdma) on a multimode phone

Measured Conducted Error Ratios of Mobile Phones (no UWB)

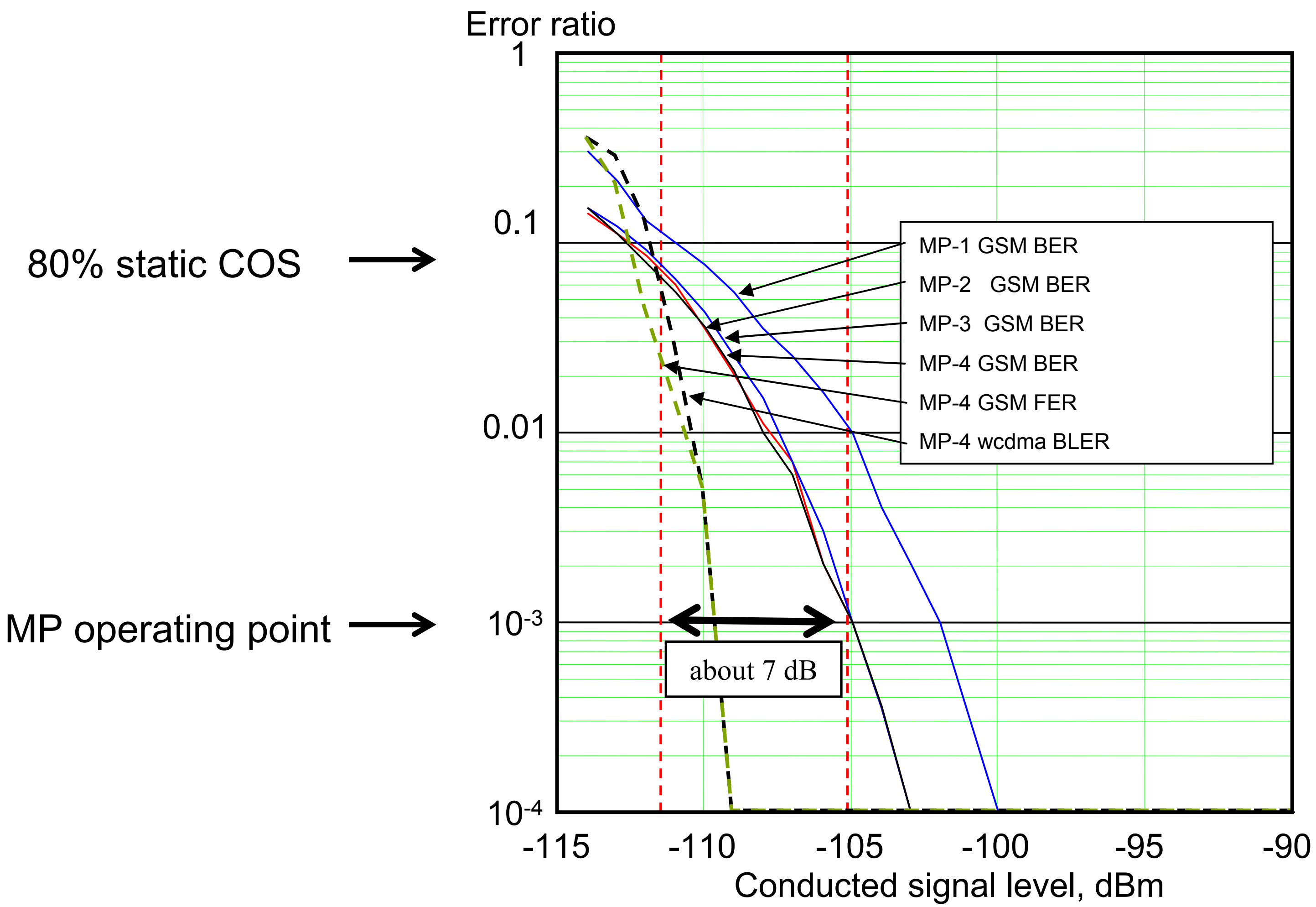


Figure 6 – Measured conducted error ratios for mobile phones

Understanding the Conducted Results

In the shielded fixture:

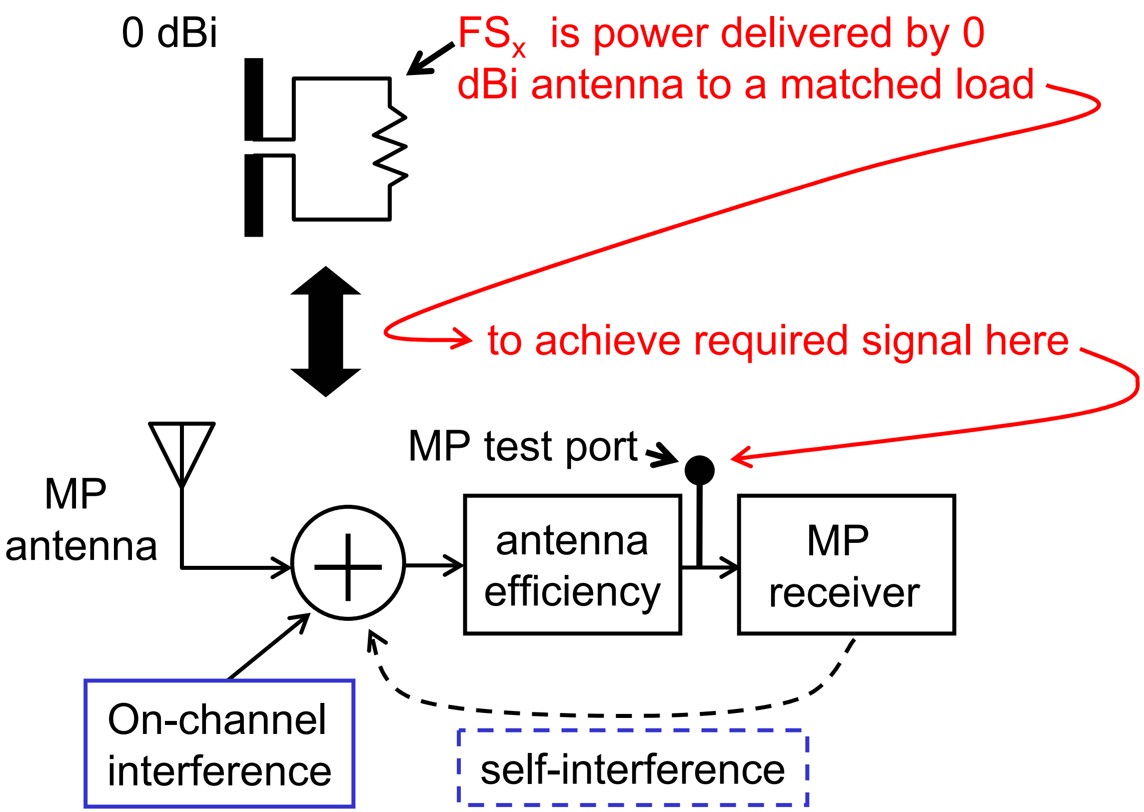
- We found that the 8 – 10 % bit error ratio level roughly corresponds to the to the 80% call originate sensitivity (COS), [equals -112 dBm in Figure 6]
- An additional 7 dB needed to get to 10^{-3} BER, [-105 dBm]
- The wcdma BLER is roughly the same as the GSM FER for the MP-2 tested
- 3 of 4 GSM phones showed nearly identical performance; the MP-1 phone was 3 dB less sensitive at 10^{-3} BER

- Based on the measured error ratio curves of Figure 6 an additional 7 dB of signal is needed to achieve "can you here me now? ... Good!" MP operation

Radiated Signal Measurement Procedure Call Setup

- Use equipment configuration “A” in Figure 1
- Test mobile phone is at [M] mounted on water-filled [Siwiak 1998] test fixture, see Figure 3
- UWB signal is OFF
- Set Wireless Test Set parameters to match Mobile Phone (MP) being tested
- Send “call originate signal” (COS) at high level (equivalent to -80 dBm at receiver)
- When MP “rings” begin test

The MP Signal Reference Model



Approximately 20 dB needs to be added to $FS_{conducted}$ 80% COS to have enough signal to mitigate the effects of:

- 80% COS to usable call
- Antenna efficiency
- Self-interference (self de-sensitization)
- On-channel interference

Thus:

FS_{cell} = -91 dBm

At the -91 dBm reference signal level a UWB signal < 1 m distance and at FCC limit level has no harmful effect in the most marginal MP coverage areas

How We Measure MP Radiated Sensitivity

UWB Tx [off], equipment configuration Figure 5

1. MP power level is referenced to a signal received by a 0 dBi antenna
2. Synchronize MP at high signal level, -80 dBm
3. Step Wireless Test Set transmit level down in 2 dB increments send COS to obtain at least three successes in a row
4. Record the failed signal level = FSo
5. Re-synchronize the MP with COS = -80 dBm
6. Starting at FSo - 2dB, obtain 3 successful calls in a row
7. Reduce COS in 1 dB increments while obtaining 3 calls in a row
8. Record the last occurrence, lowest signal level obtained for three successful calls in a row as FSo dBm
9. The conducted COS sensitivity is FSo dBm

Radiated Signal Measurement Procedure: (UWB at 3 m and 1 m)

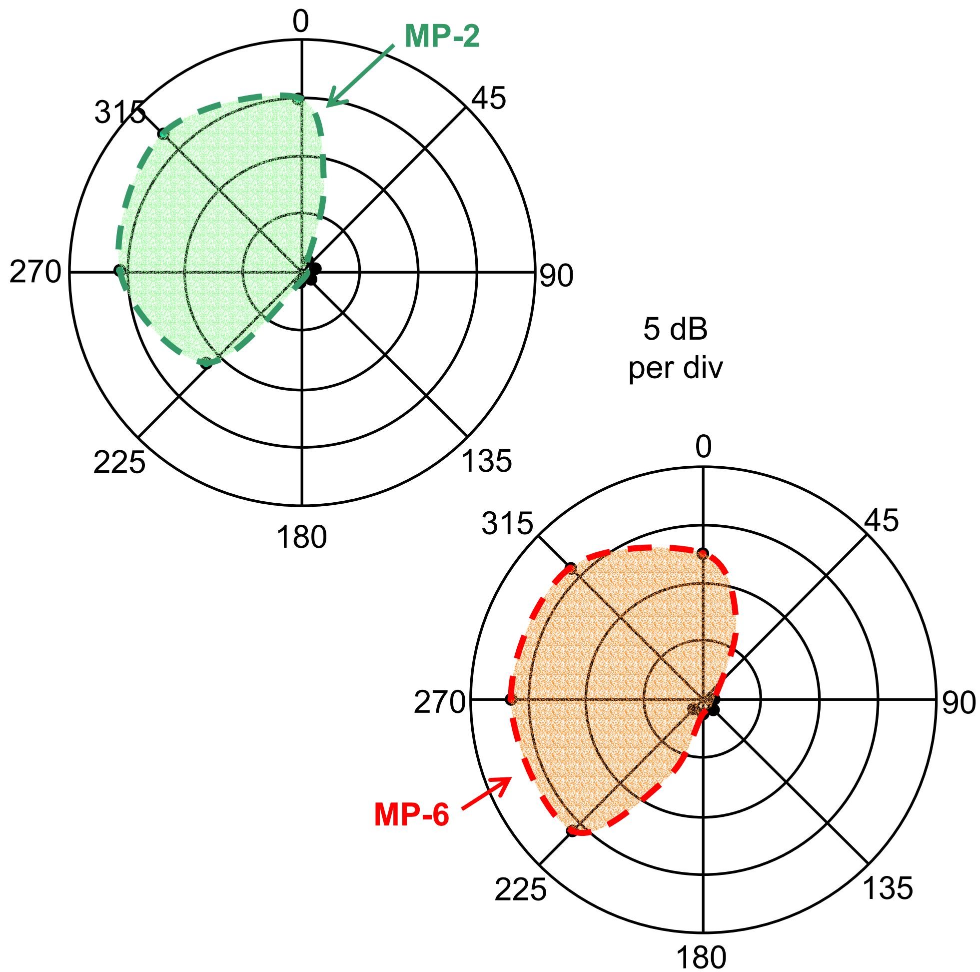
Set UWB transmitter to -53.3 dBm/MHz EIRP

- Same procedure as for no UWB
- Record MP COS sensitivity with UWB at 3 m = FS_{3m} dBm

Set UWB transmitter to -43.3 dBm/MHz EIRP to simulate 1 m distance

- Same procedure as for no UWB
- Record MP COS sensitivity with UWB at 1 m = FS_{1m} dBm

Factoring in Receiver Antenna Patterns



- Antenna patterns measured in *receiver* mode on Phantom Head device
- *Average Sensitivity*, see [Siwiak1998] found from:

$$S_{average} = 10 \log \left[\frac{8}{\sum_{i=1}^{8} \frac{1}{10^{FSi}}} \right]$$

- Peak to average is 3.1 to 5.2 dB
- Efficiency is -3 dB, [LPD2005]
- See [CTIA2003] for definitions of 3-D antenna patterns

Error Ratios of GSM MP

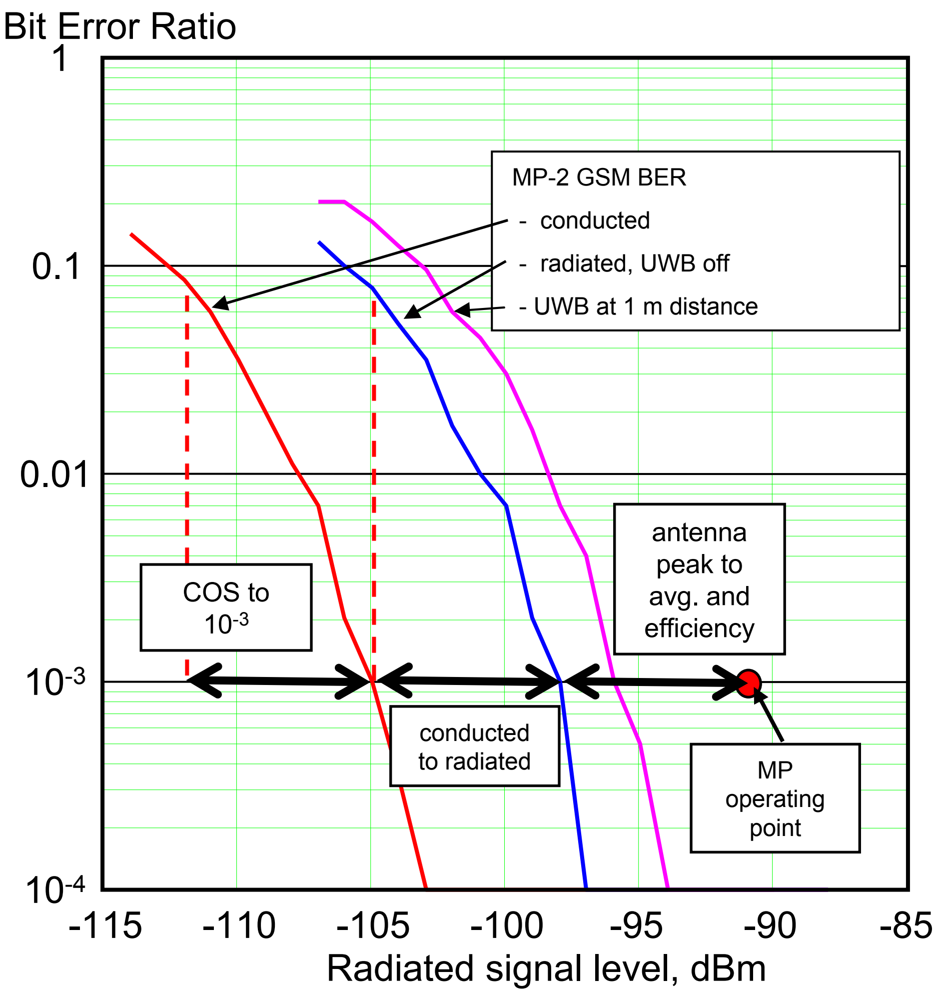


Figure 7 – Error ratios for a GSM mobile phone

- Phone operates at 1.9 GHz
- Same GSM phone used for conducted, and radiated test
- UWB at 1 m affects phone by 1 to 2 dB at the -96 dBm level
- Cell design for acceptable phone usage requires a signal level of -91 dBm (as received by a 0 dBi antenna)

Radiated Error Ratios of CDMA2000 MP

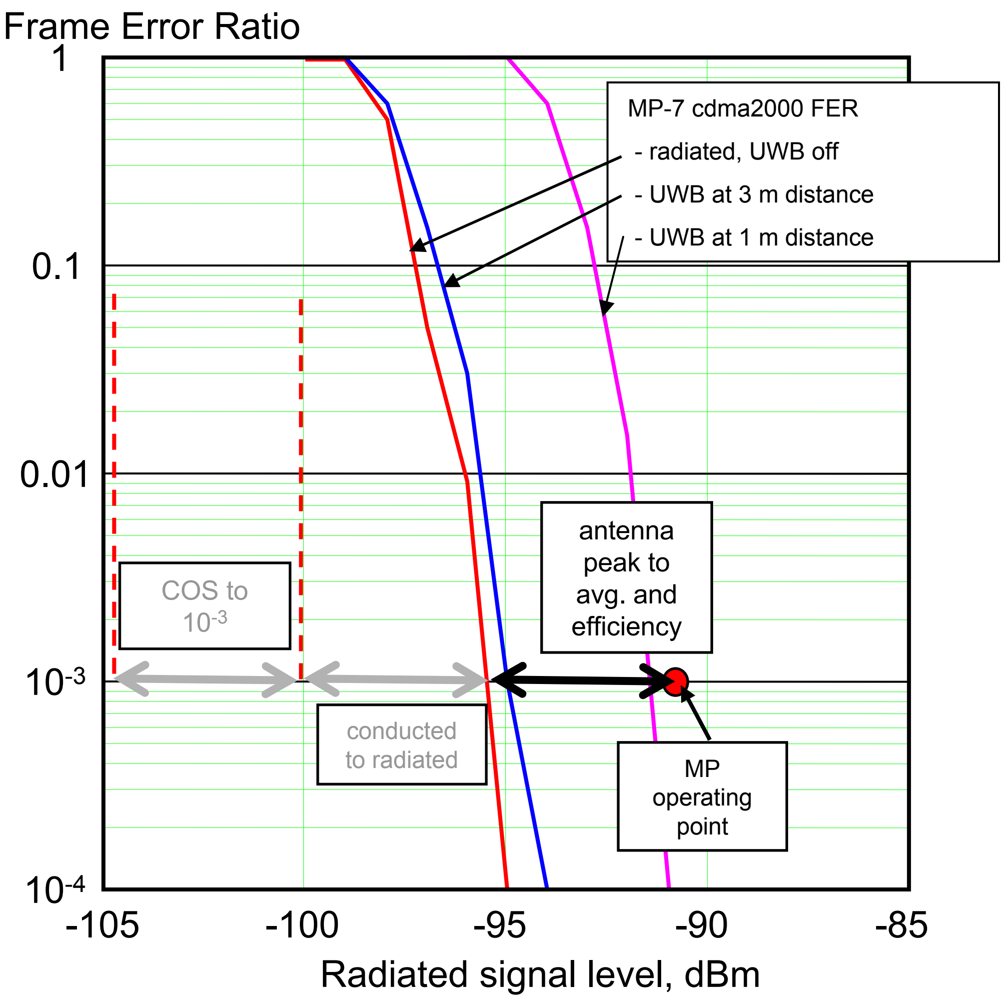


Figure 8a – Error ratios for a cdma2000 mobile phone

- Phone operates at 1.9 GHz *with just one CDMA code radiated.*
- A cdma2000 phone used for radiated tests
- UWB at 3 m affects phone by 1 dB at the -95 dBm level
- UWB at 1 m affects phone at the -92 dBm level
- Cell design for acceptable phone usage requires a signal level of -91 dBm (as received by a 0 dBi antenna)

CDMA Code Effects in CDMA Systems

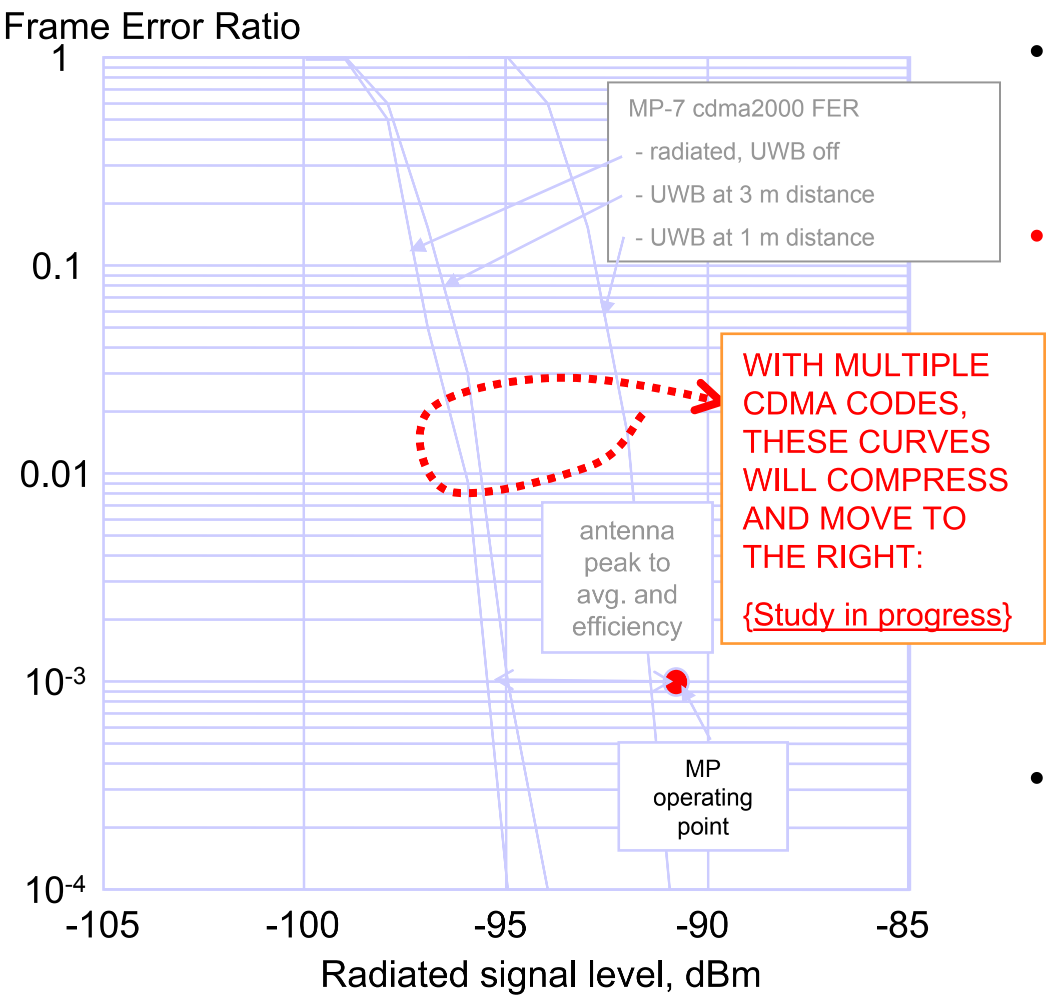


Figure 8b – Error ratios for a cdma2000 mobile phone

- MPs in deployed real CDMA systems see noise due to other MP's signaling codes
- *Adding multiple CDMA codes degrades MP sensitivity according to MP's ability to "process out" non-orthogonal signal components. Real systems operate this way!*

  At the realistic operating point shown, UWB does not change MP performance
- At the realistic MP operating point, CDMA system codes still interfere with MP operation, but not UWB

Not All Effects are Linear

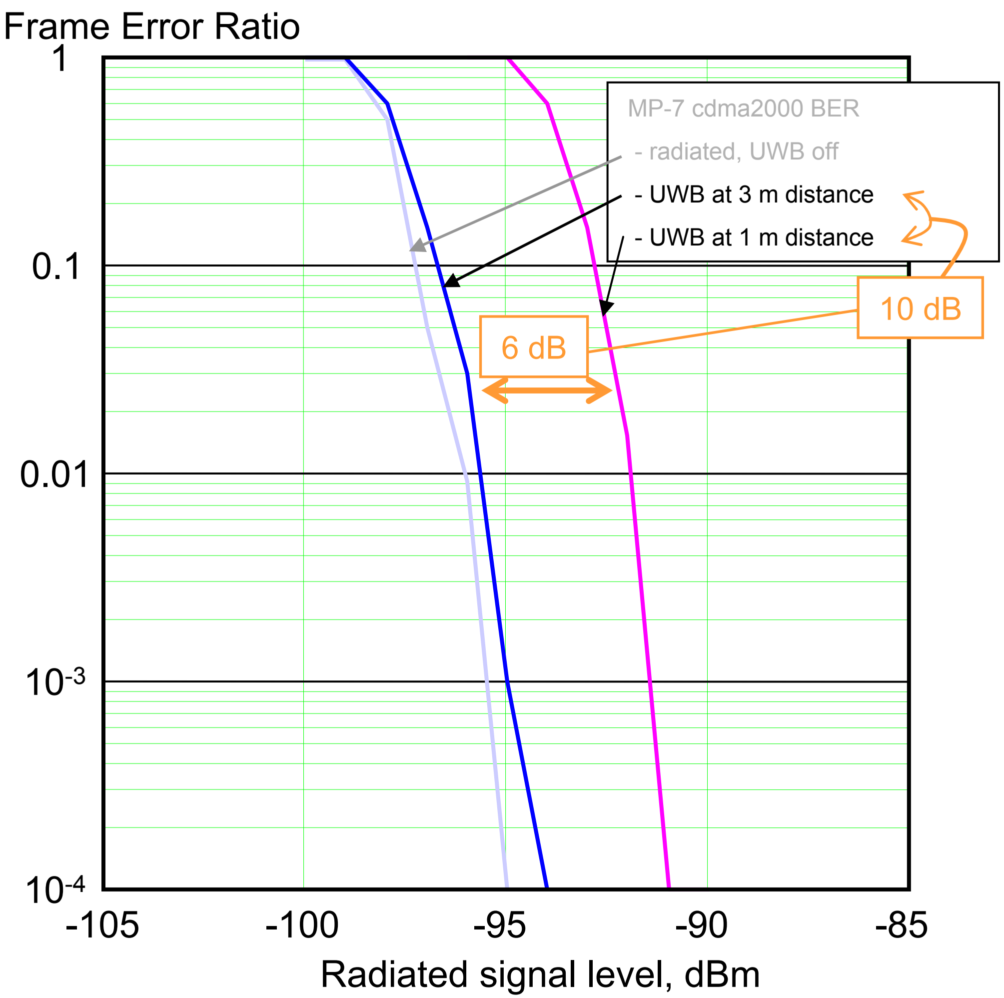


Figure 8c – Not all effects are linear.

- Note that a 10 dB change in UWB signal level resulted in just 6 dB change in cell-phone performance
- This happens because the UWB noise (which we changed) is added to the effective noise floor of the cell-phone (the LNA noise plus self-desensitization noise) which is not changing: so the total noise changes by 6 dB.

Understanding the Results

In static conditions, at the peak antenna gain antenna of the MP on the Phantom Head Fixture (see Fig 2b and Fig 3):

- FS dBm is approximately the 80% call originate sensitivity (COS): (50% probability of getting three calls in a row, it is the *conducted sensitivity* with no UWB signal
- FSo dBm is approximately the 80% COS (50% probability of getting three calls in a row), it is the *static radiated sensitivity with no UWB* signal
- FS_{3m} dBm is the 80% COS with a *3 m distant* UWB signal at -53.3 dBm/MHz EIRP across the entire mobile phone band
- FS_{1m} dBm is the 80% COS with a *1 m distant* UWB signal at -53.3 dBm/MHz EIRP across the entire mobile phone band (simulated by a level of -43.3 dBm/MHz at 3 m)
- *Based on the measured error ratio curves, see Figure 6, an additional 7 dB of signal is needed to achieve usable MP operation*

Arriving at Operating System Sensitivity

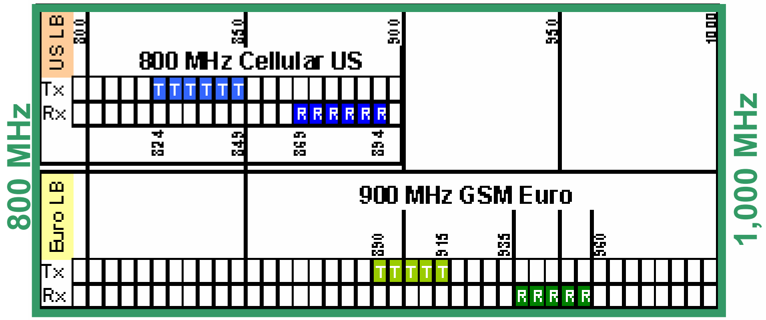
- “Conducted” is 3 of 3 COS “-112 dBm”
- “Radiated” (also 3 of 3 COS) “-102 dBm”
  - includes antenna efficiency at peak of pattern
- “3 of 3 COS” to “no errors”: 7 dB
- Pattern peak to average: 3.1 dB
- Thus, needed cell signal is: FS_{cell} = -92 dBm

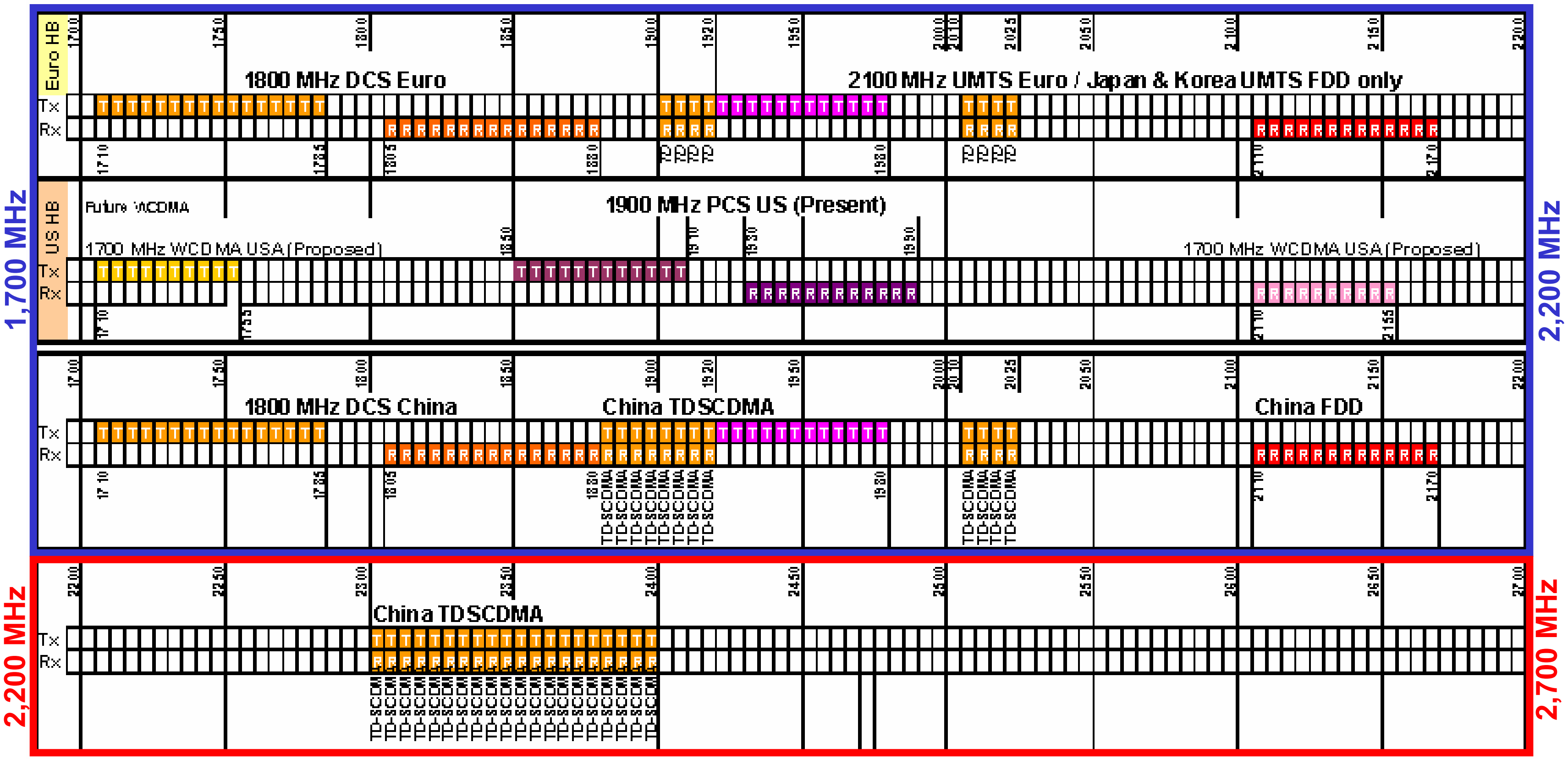
- Motion, multipath, not taken into account

What “-92 dBm” Means

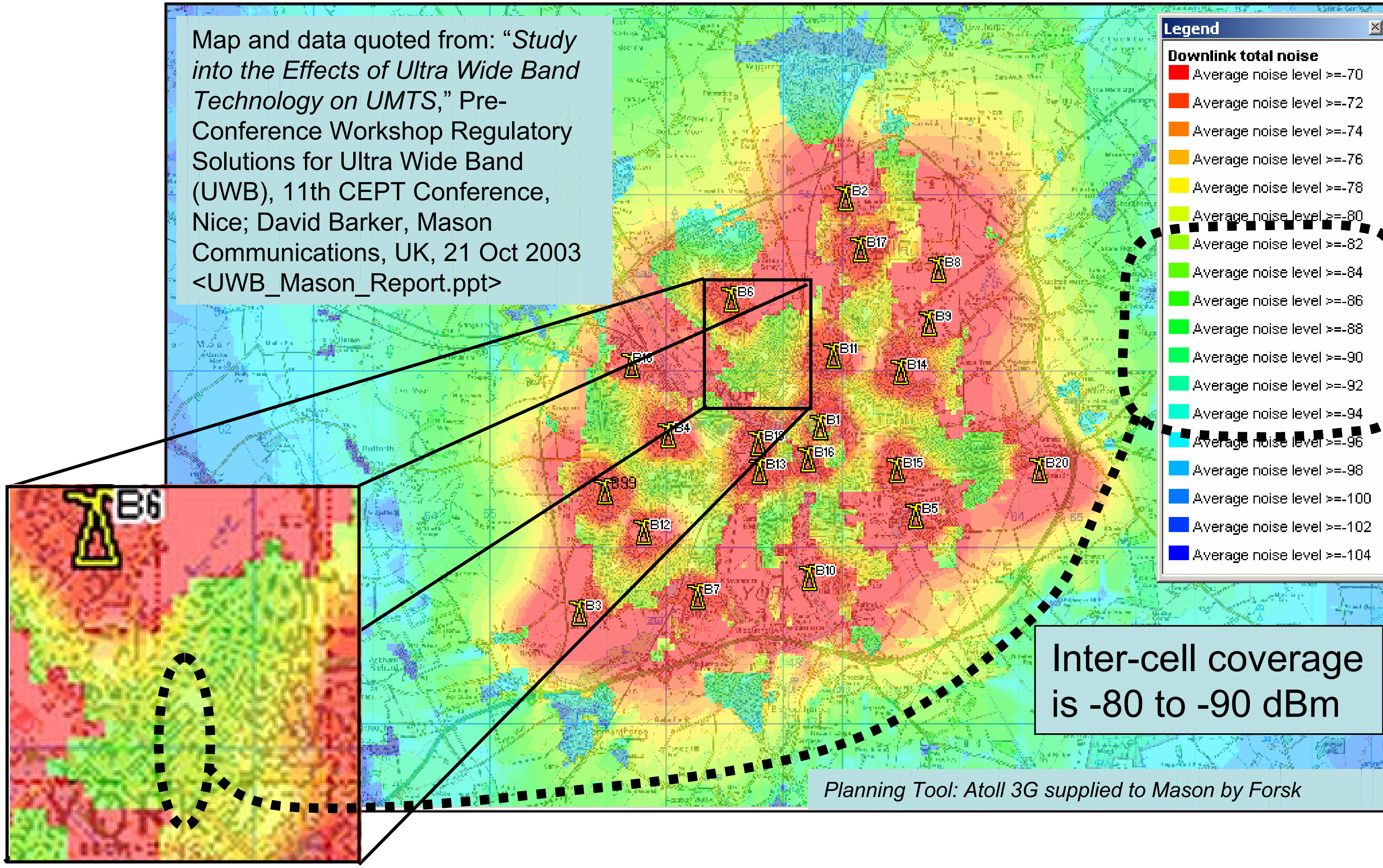
- This corresponds to a contour of coverage field strength captured by a 0 dBi antenna
- If a base station cell transmitter emits 2 watts (33 dBm) EIRP, this makes (33 + 92) = 125 dB available for system path loss
- A UMTS system is planned around inter-cell signals between -80 and -90 dBm [Mason2003]

Worldwide Cellular Operating Bands





A UMTS Coverage Map



Static Sensitivity (1.9 GHz band)

test	MP-3 GSM dBm	MP-4 GSM dBm	MP-2 GSM dBm	MP-1 GSM dBm	MP-7 cdma2000 dBm
conducted 80% COS	-112	-110	-111	-109	-109
radiated 80% COS no UWB	-102	-93	-104	-101	-96
radiated 80% COS UWB at 3 m	-101	-93	-103	-100	-95
radiated 80% COS UWB at 1 m	-95	-93	-95	-94	-92
cell operating point (radiated + efficiency + peak to avg)	-92	-90	-91	-89	-89

Cell operating point requires stronger signal than level than UWB coexistence point

Static Sensitivity (1.9 GHz band)

test	MP-3 GSM dBm	MP-4 GSM dBm	MP-2 GSM dBm	MP-1 GSM dBm	MP-7 cdma2000 dBm
conducted 80% COS	-112	-110	-111	-109	-109
radiated 80% COS no UWB	-102	-93			
radiated 80% COS UWB at 3 m	-101	-93			
radiated 80% COS UWB at 1 m	-95	-93			
cell operating point (radiated + efficiency + peak to avg)	-92	-90			

NOTE: When the MP sensitivity is already low, the UWB signal has no effect;

UWB not a factor at sensible operating point

Cell operating point requires stronger signal than level than UWB coexistence point

Conclusions

Measurements of several CDMA-2000 and GSM cell-phones show:

- *Radiated* sensitivities for usable performance are far poorer—by 20 dB—than phones signaled at their test ports (conducted test)
  - This is due to antenna inefficiency and self-interference
- A weak-signal operating level (where the audio break-ups but still allows a conversation) corresponds to -89 to -91 dBm (at the output of a 0 dBi antenna)
- Cell-phones have more interference immunity than shown in these measurements - Additional cell system signal margin, not included here, is needed for
  - Multipath fading
  - Mobility
  - Code-noise
  - RFI
- **The FCC's -53.3 dBm/MHz EIRP level in the 1.8-1.9 GHz bands is conservative and correct**
  - At a usable operating point for mobile phones, noise-like UWB signals at the -53.3 dBm/MHz EIRP level do not cause harmful interference to mobile phones in the 1.8 and 1.9 GHz bands

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