RF Exposure Test Procedures

- Review & Update -

FCC / OET

Laboratory Division

October 2007

TCB Workshop

Overview

- 802.11 a/b/g SAR Procedures
  - highest output power channels vs. power reduction at band edge
- 3 – 6 GHz SAR Measurements
  - update on areas of concerns
- SAR Probe Calibration and System Verification
  - considerations for new & evolving wireless technologies
- 3GPP Release 6
  - SAR procedures
- Test Reduction Procedures for Laptop Computers
  - multiple transmitters on display screens

3 – 6 GHz SAR Measurements

- standards are still in progress
  - IEEE 1528b
  - IEC 62209-2
  - procedures are insufficient for most new digital technologies with noise-like modulations & high PAR
- measurement concerns
  - probe calibration
  - tissue dielectric liquid recipes
  - broadband applications
  - system accuracy verification
  - SAR scan procedures

SAR Probe Calibration

&

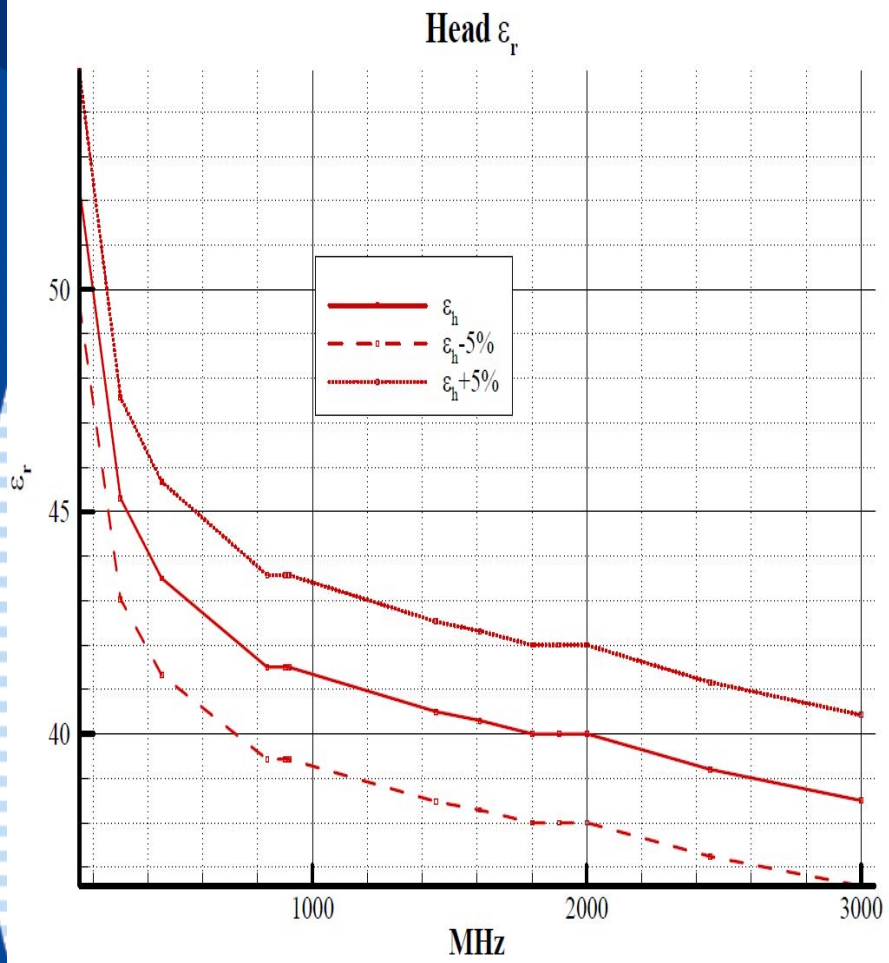
System Verification

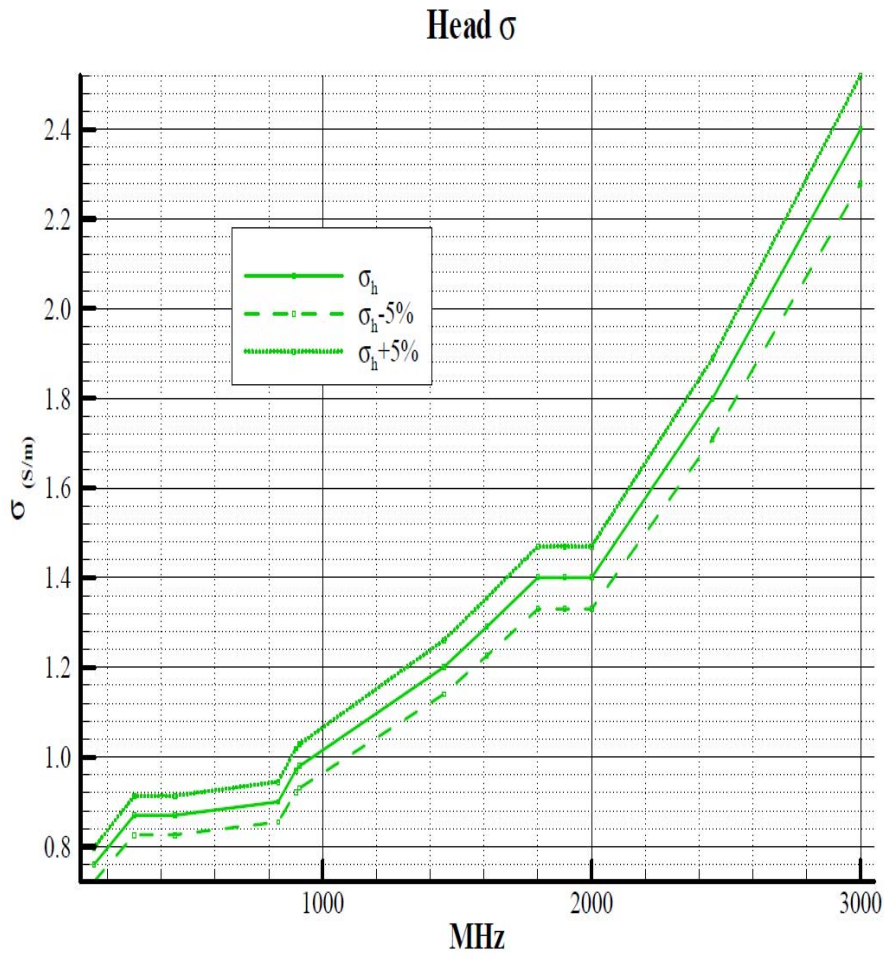
150 MHz – 3 GHz

SAR Probe Calibration

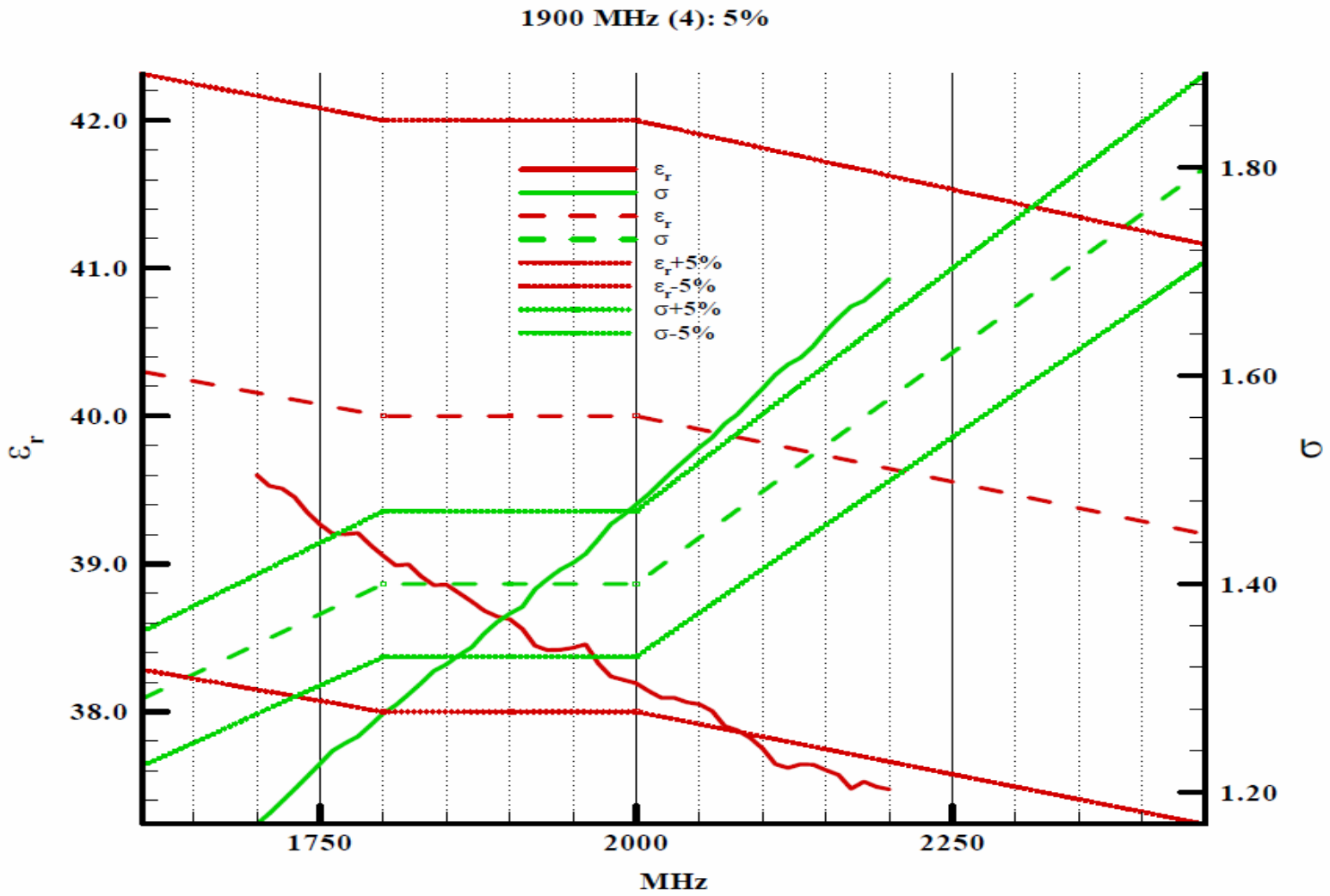
- valid frequency range of a probe calibration
  - varies with probe design & its frequency characteristics
  - depends on tissue liquid recipe used during calibration
    - frequency & temperature vs. dielectric characteristics
  - determined by calibration frequency and bandwidth
- valid frequency range of SAR measurements
  - dictated by the validity of probe calibration range
  - depends on liquid characteristics used during the measurement
  - determined by effective bandwidth and valid calibration range
- acceptable vs. unacceptable SAR measurements
  - how to conduct system verification?
  - what if procedures or required components are unavailable?
    - such as dipole or liquid etc.

Dielectric Parameter Tolerances





Tissue Characteristics Issues



Probe Calibration Considerations

- general requirements
  - < 300 MHz: ± 50 MHz of probe calibration point
  - 300 MHz – 3 GHz: ± 100 MHz of probe calibration point
- additional considerations
  - measurements exceed 50% of general requirements, ± 25/50 MHz
    - know the actual tissue dielectric parameters for probe calibration
      - differences in ε and σ for probe calibration & measurement ≤ 5%
      - also, ε and σ for both probe calibration & measurement should be within 5% of required target dielectric parameters
    - only nominal dielectric values specified for probe calibration
      - ε < target and σ > target for liquid used in measurement, or
      - thorough analysis of probe & tissue effective frequency intervals
      - alternatively, compensate SAR with +5% change in ε and -5% change in σ according to valid SAR sensitivity data

SAR System Verification

- reference dipoles definitions
  - according to IEEE 1528 (1528b/IEC 62209-2 draft) specifications
  - other dipoles need vigorous numerical & experimental validation by manufacturers similar to IEEE 1528 implementations
  - 1-g SAR within 10% of target and peak SAR within 15%
  - for non-standard sources: submit filing to FCC
- the useful frequency range of reference dipoles depends on
  - dipole operating characteristics – bandwidth, return loss etc.
  - availability of target SAR values at desired frequencies
  - probe calibration frequency
  - tissue dielectric characteristics
  - typical bandwidth: ± 50 MHz < 300 MHz; ± 100 MHz > 300 MHz
- BW, dipole & device test frequencies are often misaligned

Alternative Dipole Procedures

- dipole alternative method A
  - > 1.5 – 2 GHz: -15 dB return loss provides about 150 – 200 MHz
    - SAR target values may be established at multiple frequencies
      - require measured SAR within 15% of manufacturer calibrated target
      - require long term coefficient of variation < 3% (std. dev. / mean < 0.03)
- dipole alternative method B
  - < 1.5 GHz: -15 dB return loss is limited to about 15 – 100 MHz
    - need to operate dipole within its resonance frequency range
    - use the tissue recipe required for testing device at nearby frequencies but outside of the dipole resonance frequency range
      - dielectric parameters of most tissue recipes are generally within ± 10% of the required target values for ± 100 – 250 MHz
      - using SAR probes calibrated within the device test frequency range
      - establish SAR targets for the specific setup (probe, tissue & dipole)
    - conduct system verification at dipole frequency
      - with device frequency probe calibration and tissue dielectric properties

Alternative Method B

alternative B is for interim use only and requires

- vigorous validation of the setup and SAR target value
- tissue parameters for dipole & device frequencies to be within 10%
- dipole SAR at device & dipole frequencies to be within 10 – 15%
- SAR changes due to differences in probe conversion factor between device & dipole frequencies < 5%
- approximate (effective) frequency range for Method B
  - ± 120 – 250 MHz at > 300 MHz
  - ± 100 MHz at < 300 MHz
- establish initial SAR target with 5 or more independently measurements
  - coefficient of variation < 2% (0.02)
- must subsequently use the same liquid recipe and probe calibration
  - subsequent coefficient of variation < 3%
  - mean SAR should be within 15% of initially measured target value
- include all results and analyses in test report

3GPP SAR Procedures

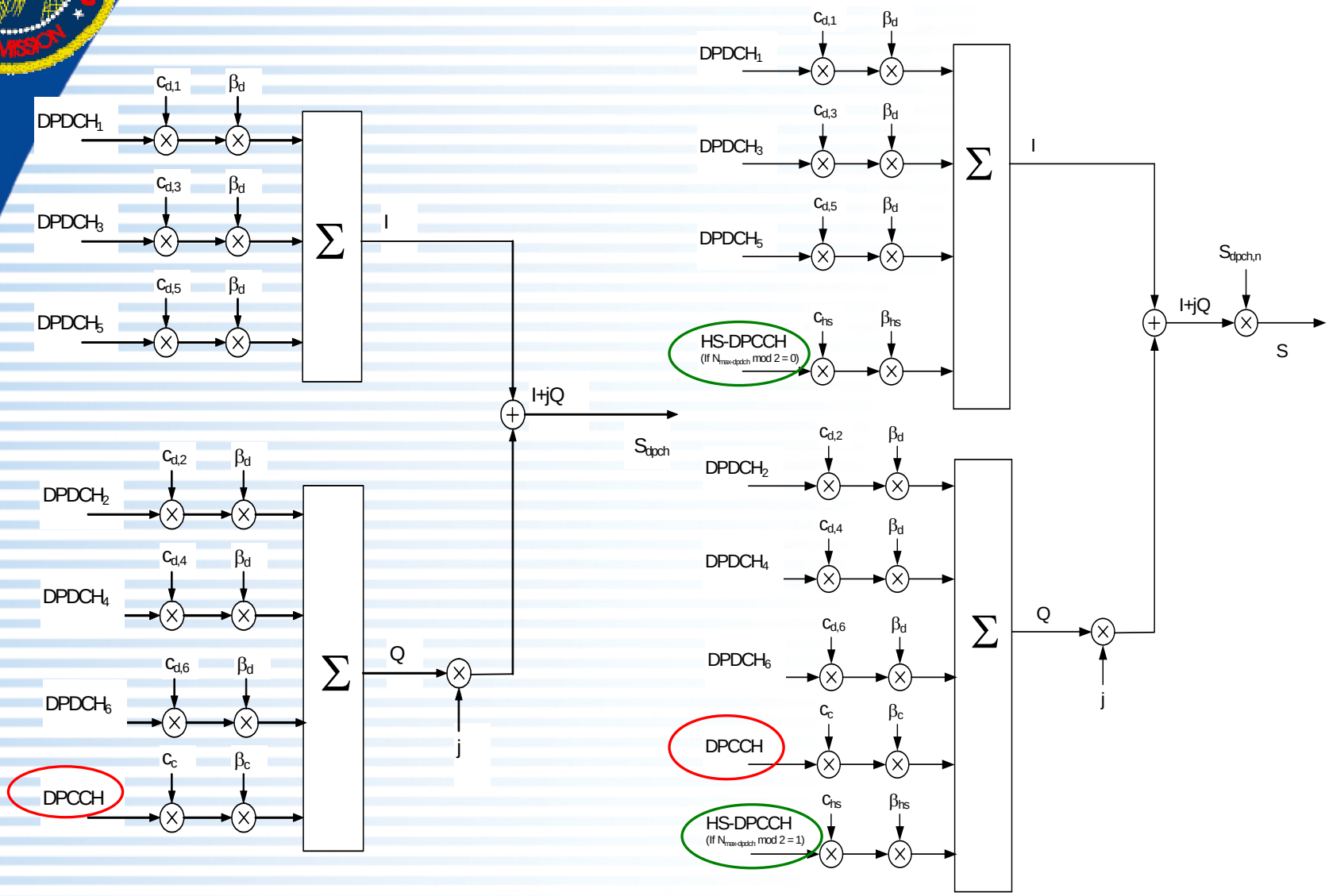
- WCDMA/HSDPA/HSPA –

R 99, R 5 & R 6

Overview

- applying systematic approaches to determine SAR test requirements according to
  - 3GPP loopback test modes
  - output power measurements
    - in various operating modes and code channel combinations
    - to reduce unnecessary or redundant SAR tests
  - device operating capabilities and exposure conditions
    - streamline head and body exposure or SAR evaluation
- updated earlier SAR procedures for R99 & R5 to include R6 HSPA
  - provided interim R6 SAR procedures, without R6 protocol details
  - updated R99 & R5 procedures to streamline with R6 protocols
  - noticed test configuration issues in initial R6 filings & reports
    - due to test equipment availability issues
    - lack of understanding for R6 (3GPP) protocols & operations

WCDMA / HSDPA

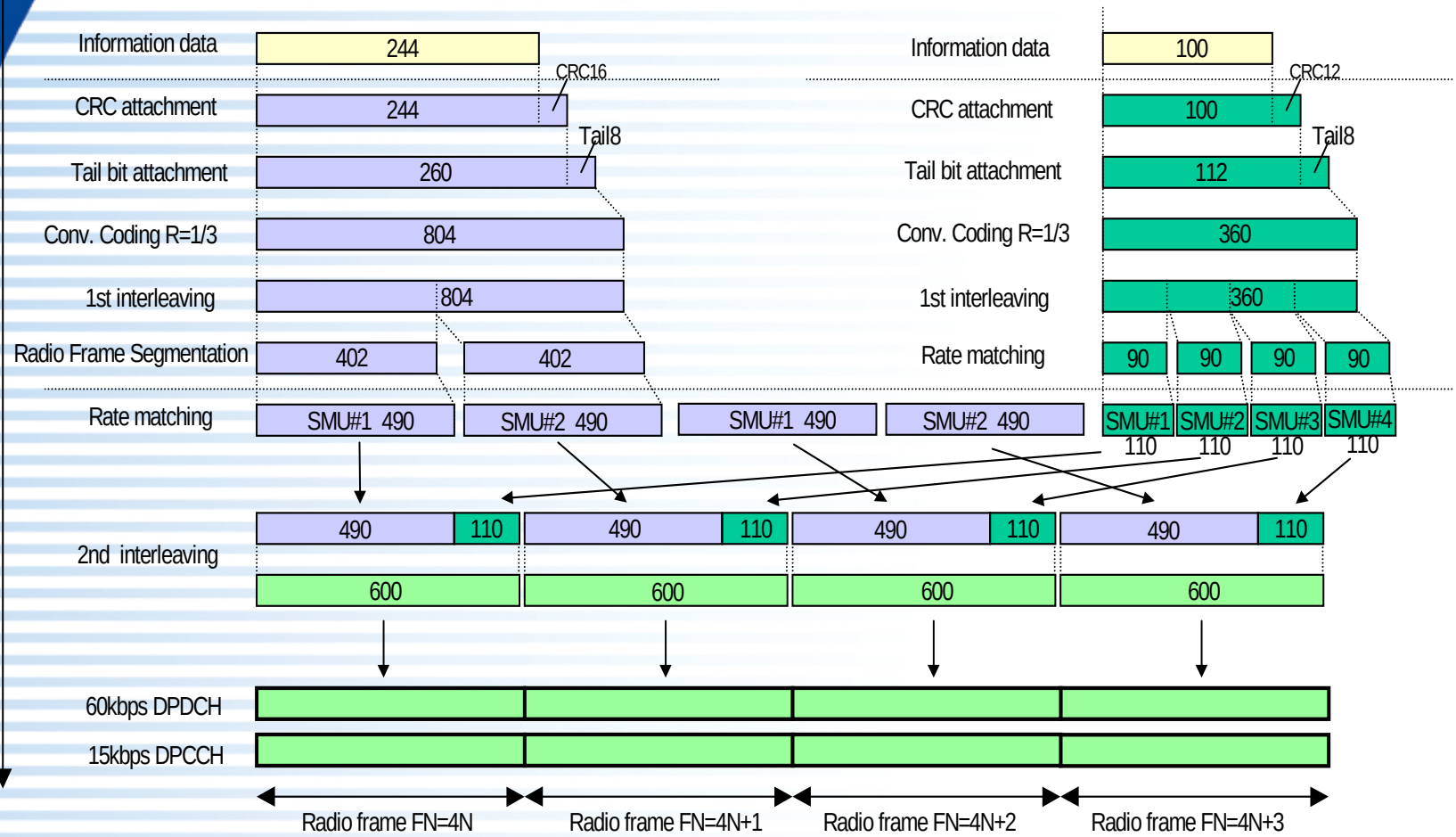

$C_{d,1}$
β_d
DPDCH1
$C_{d,3}$
β_d
DPDCH3
$C_{d,5}$
β_d
DPDCH5
Σ
I
$C_{d,2}$
β_d
DPDCH2
$C_{d,4}$
β_d
DPDCH4
$C_{d,6}$
β_d
DPDCH6
C_c
β_c
DPCCH
Σ
Q
j
I+jQ
S_{dpch}
C_{hs}
β_{hs}
HS-DPCCH
(If $N_{max-dpdch}$ mod 2 = 0)
HS-DPCCH
(If $N_{max-dpdch}$ mod 2 = 1)
$S_{dpch,n}$
S

Channelization Codes

	Channel Bit Rate (kbps)	Channel Symbol Rate (ksps)	Spreading Factor	Spreading Code Number	Bits/Slot
DPCCH	15	15	256	0	10
	15	15	256	64	10
	30	30	128	32	20
	60	60	64	16	40
$DPDCH_1$	120	120	32	8	80
	240	240	16	4	160
	480	480	8	2	320
	960	960	4	1	640
$DPDCH_n$	960	960	4	1, 2, 3	640

12.2 kbps RMC

DPCCH/DPDCH power ratio = β_c / β_d = -5.46 dB



HSDPA

- FRC (fixed reference channels)
  - UE Categories
  - IR (incremental redundancy)
  - HARQ (hybrid automatic request)
- VFC (variable reference channels)
  - uplink measurements & AMC (adaptive modulation & coding)
  - multiple code channels on HS-PDSCH

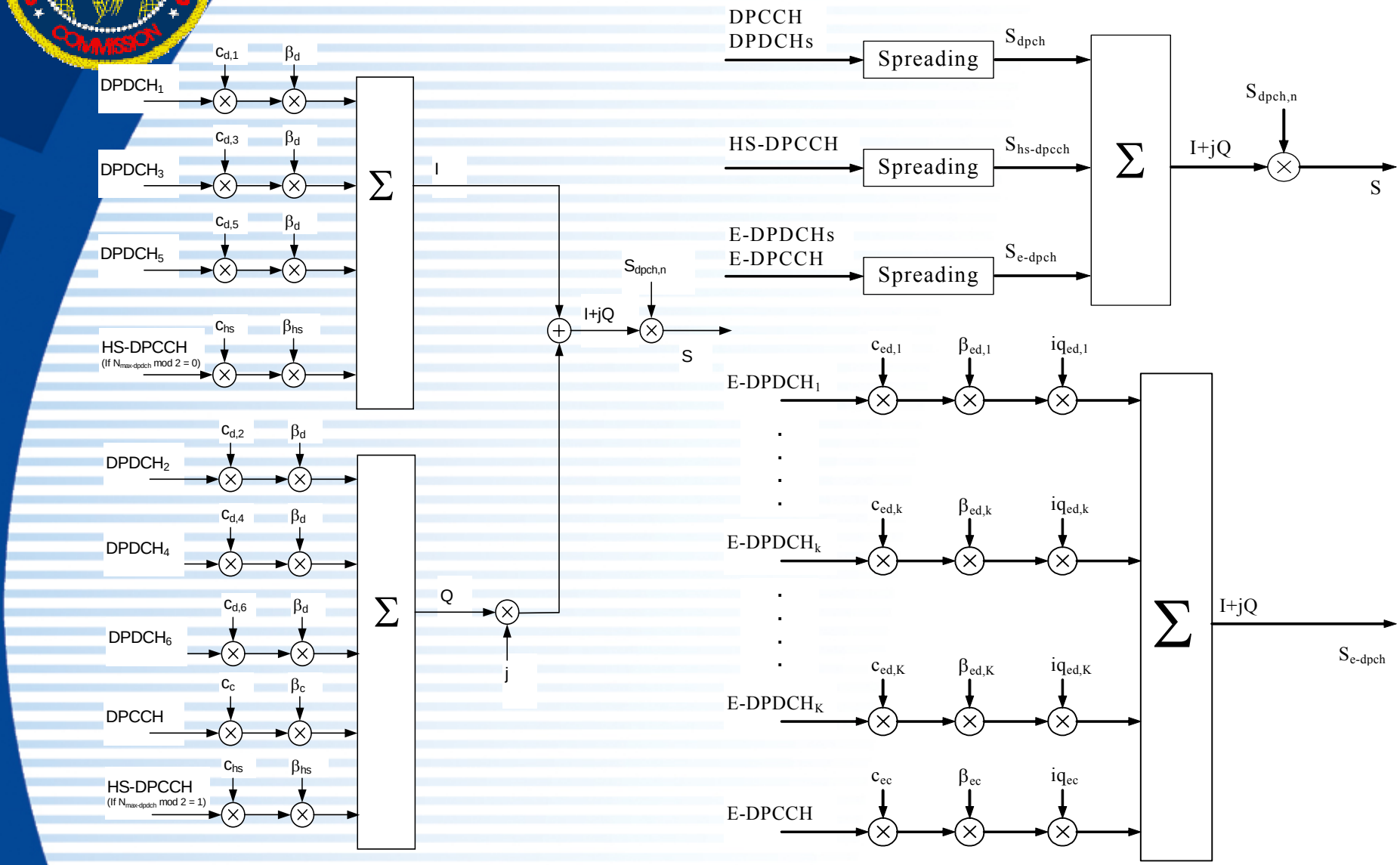
Sub-test	β_c	β_d	β_d (SF)	β_c/β_d	β_{hs} (1)	CM (dB) (2)
1	2/15	15/15	64	2/15	4/15	0.0
2	12/15 (3)	15/15 (3)	64	12/15 (3)	24/15	1.0
3	15/15	8/15	64	15/8	30/15	1.5
4	15/15	4/15	64	15/4	30/15	1.5

Note 1: Δ_{ACK}, Δ_{NACK} and $\Delta_{CQI} = 8 \Leftrightarrow A_{hs} = \beta_{hs}/\beta_c = 30/15 \Leftrightarrow \beta_{hs} = 30/15 * \beta_c$

Note 2: CM = 1 for β_c/β_d =12/15, β_{hs}/β_c=24/15.

Note 3: For subtest 2 the β_c/β_d ratio of 12/15 for the TFC during the measurement period (TF1, TF0) is achieved by setting the signaled gain factors for the reference TFC (TF1, TF1) to β_c = 11/15 and β_d = 15/15.

WCDMA / HSPA


DPCCH
DPDCHs
Spreading
S_{dpch}
HS-DPCCH
Spreading
$S_{hs\text{-}dpcch}$
E-DPDCHs
E-DPCCH
Spreading
$S_{e\text{-}dpch}$
Σ
I+jQ
$S_{dpch,n}$
S
$DPDCH_1$
$DPDCH_3$
$DPDCH_5$
HS-DPCCH
(If $N_{max\text{-}dpdch}$ mod 2 = 0)
$c_{d,1}$
$c_{d,3}$
$c_{d,5}$
c_{hs}
β_d
β_{hs}
I
$DPDCH_2$
$DPDCH_4$
$DPDCH_6$
DPCCH
HS-DPCCH
(If $N_{max\text{-}dpdch}$ mod 2 = 1)
$c_{d,2}$
$c_{d,4}$
$c_{d,6}$
c_c
β_c
Q
j
$E\text{-}DPDCH_1$
$E\text{-}DPDCH_k$
$E\text{-}DPDCH_K$
E-DPCCH
$c_{ed,1}$
$c_{ed,k}$
$c_{ed,K}$
c_{ec}
$\beta_{ed,1}$
$\beta_{ed,k}$
$\beta_{ed,K}$
β_{ec}
$iq_{ed,1}$
$iq_{ed,k}$
$iq_{ed,K}$
iq_{ec}
$S_{e\text{-}dpch}$

E-DPDCH Channels

Configuration	DPDCH	HS-DPCCH	E-DPDCH	E-DPCCH
R99 + HSDPA (R5)	6	1	-	-
R99 + HSDPA + HSUPA	1	1	2	1
HSDPA + HSUPA	-	1	4	1

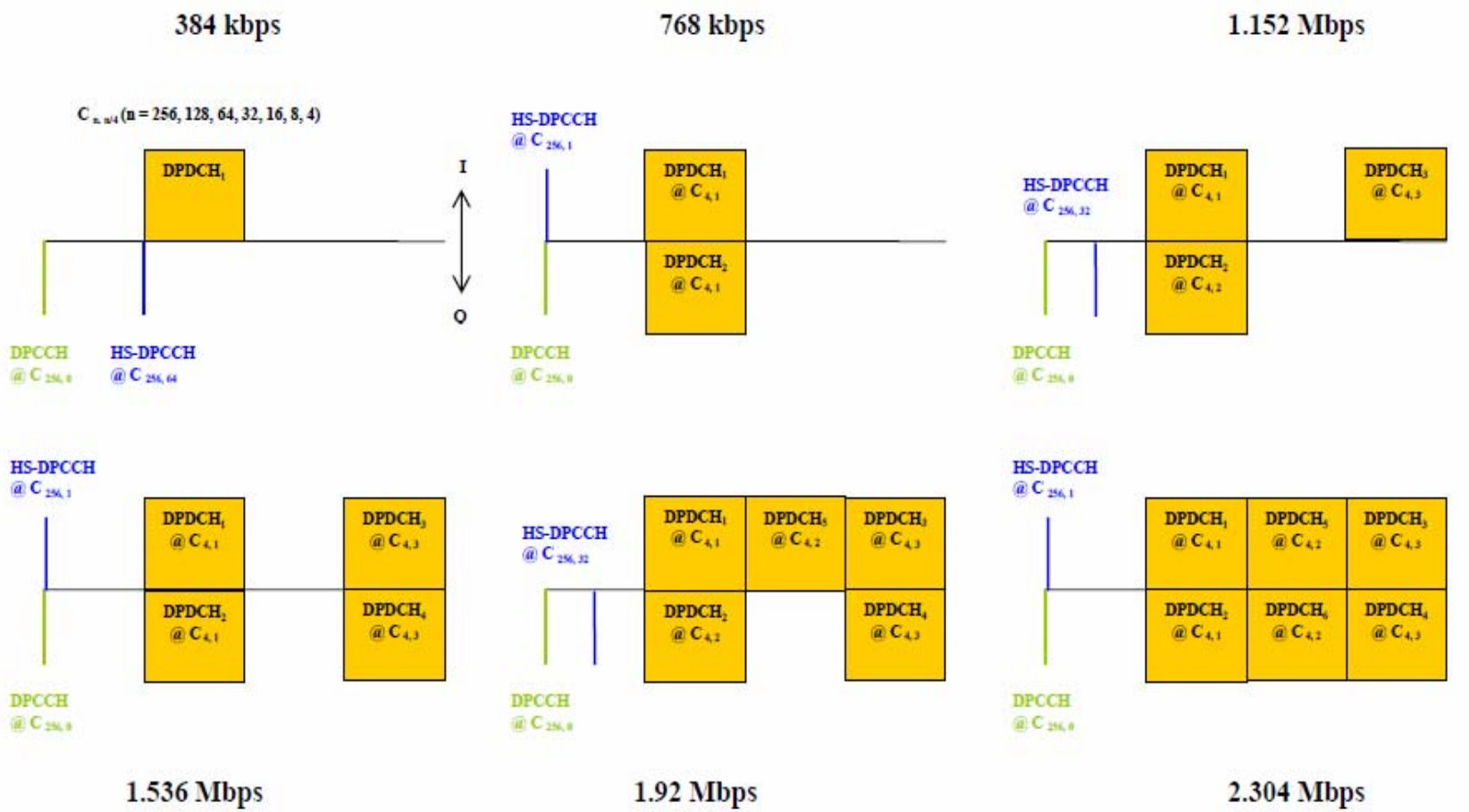
$N_{max\text{-}dpdch}$	$E\text{-}DPDCH_k$	Channelization Code $C_{ed,k}$
0	$E\text{-}DPDCH_1$	$C_{ch,SF,SF/4}$ if SF ≥ 4; $C_{ch,2,1}$ if SF = 2
	$E\text{-}DPDCH_2$	$C_{ch,4,1}$ if SF = 4; $C_{ch,2,1}$ if SF = 2
	$E\text{-}DPDCH_3$ $E\text{-}DPDCH_4$	$C_{ch,4,1}$
1	$E\text{-}DPDCH_1$	$C_{ch,SF,SF/2}$
	$E\text{-}DPDCH_2$	$C_{ch,4,2}$ if SF = 4; $C_{ch,2,1}$ if SF = 2

E-DPDCH Parameters

UE E-DCH Category	Maximum E-DCH Codes Transmitted	Number of HARQ Processes	E-DCH TTI (ms)	Minimum Spreading Factor	Maximum E-DCH Transport Block Bits	Max Rate (Mbps)
1	1	4	10	4	7110	0.7296
2	2	8	2	4	2798	1.4592
	2	4	10	4	14484	
3	2	4	10	4	14484	1.4592
4	2	8	2	2	5772	2.9185
	2	4	10	2	20000	2.00
5	2	4	10	2	20000	2.00
6 (No DPDCH)	4	8	2	2 SF2 & 2 SF4	11484	5.76
	4	4	10		20000	2.00
7 (No DPDCH)	4	8	2	2 SF2 & 2 SF4	22996	?
	4	4	10		20000	?

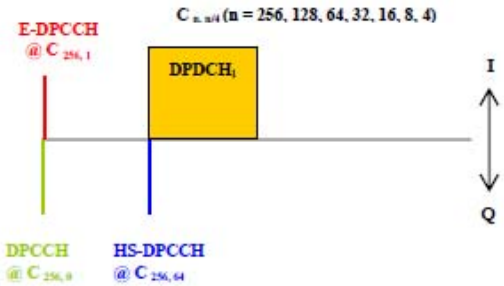
NOTE: When 4 codes are transmitted in parallel, two codes shall be transmitted with SF2 and two with SF4.
UE Category 1 to 6 support QPSK only. UE Category 7 supports QPSK and 16QAM. (TS 25.306-7.3.0)

DPDCH & HS-DPCCH

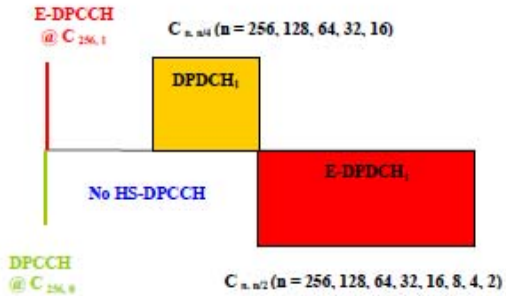


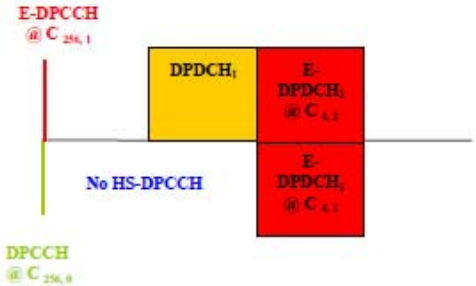
DPDCH, HS-DPCCH & E-DPDCH

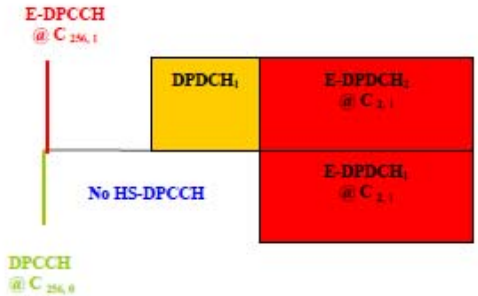
UE CAT: 1, 3, 5: 10 ms TTI only
UE CAT: 2, 4, 6: 2 or 10 ms TTI

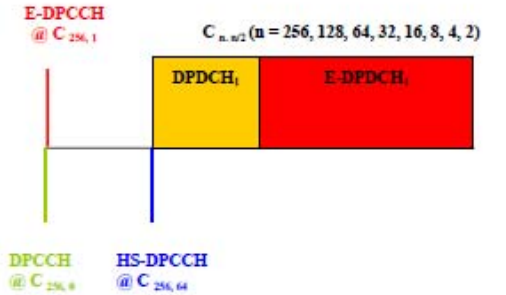


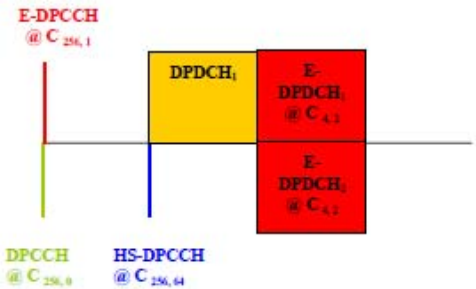
1:	UE CAT 1, 2, 3, 4, 5
2:	UE CAT 1, 3, 5 @ 10 ms TTI
	UE CAT 2, 4 @ 2 or 10 ms TTI
3 & 4:	UE CAT 3, 5 @ 10 ms TTI
	UE CAT 2, 4 @ 2 or 10 ms TTI
5 & 6:	UE 5 @ 10 ms TTI
	UE 4 @ 2 or 10 ms TTI

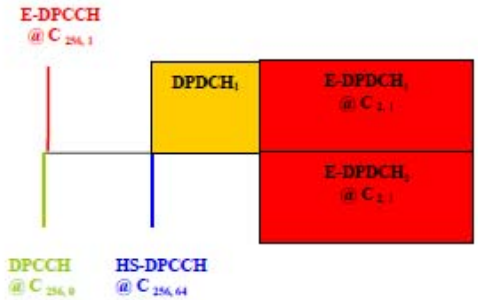






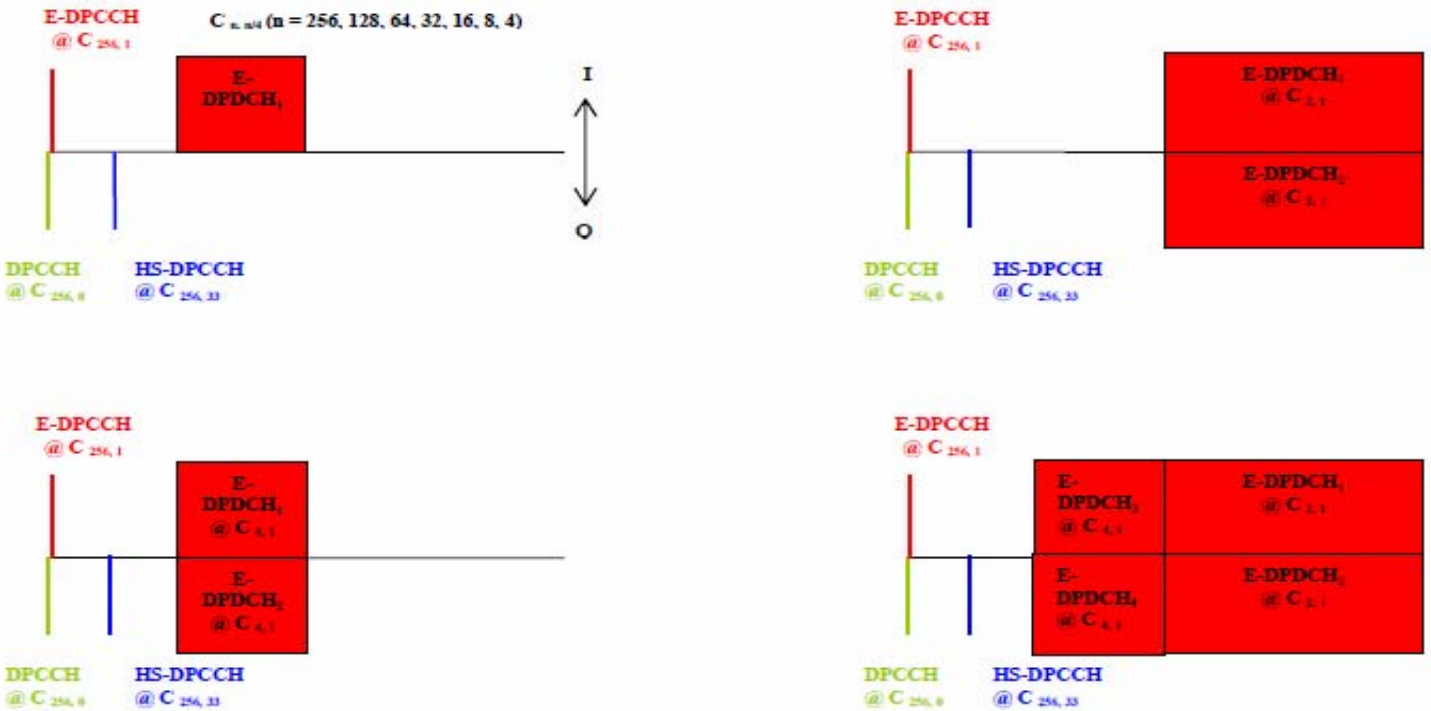






E-DPDCH without DPDCH

1: UE CAT 1, 3, 5 @ 10 ms TTI UE CAT 2, 4 @ 2 or 10 ms TTI	3: UE CAT 5 @ 10 ms TTI UE CAT 4 @ 2 or 10 ms TTI
2: UE CAT 3, 5 @ 10 ms TTI UE CAT 2 @ 2 or 10 ms TTI	4: UE CAT 6 @ 2 or 10 ms TTI



Handset SAR Procedures

- 12.2 kbps RMC in test loop mode 1 with radio link for head & body
- confirm output power for other physical channels
  - $DPDCH_n$, HSDPA, HSPA (use power control algorithm 2 for E-DCH)
  - apply other RMC, FRC and E-DCH reference configurations
  - MPR is not mandatory; therefore, may need different test procedures
- additional head SAR
  - 12.2 kbps AMR with 3.4 kbps SRB if output is ¼ dB > 12.2 kbps RMC
- additional body SAR
  - $DPDCH_n$ if ¼ dB > 12.2 kbps RMC
    - check test equipment support issues for $DPDCH_n$
  - if following output is > ¼ dB > 12.2 RMC or 12.2 RMC SAR > 75% of SAR limit test
    - 12.2 kbps RMC + HSDPA using R5 data device SAR procedures
    - 12.2 kbps RMC + HSPA using R6 data device SAR procedures
- test additional SAR with highest SAR configuration in 12.2 RMC

Data Device SAR Procedures

- measure SAR using 12.2 kbps RMC only
  - test loop mode 1 with radio link and all bits up
- confirm output power for $DPDCH_n$, HSDPA, HSPA
- follow head & body SAR for handsets as appropriate
- if following output is ¼ dB > than 12.2 RMC or 12.2 RMC SAR > 75% of SAR limit, test
  - R5 HSDPA SAR with
    - 12.2 kbps RMC + FRC H-set 1 using R5 sub-test 1
  - R6 HSPA SAR with
    - 12.2 kbps RMC + FRC H-set 1 + E-DCH using R6 sub-test 5
    - use power control algorithm 2
    - different procedures apply if MPR implementation differs
  - using highest SAR configuration in 12.2 kbps RMC

E-DPDCH Test Parameters

Sub-test	β_c	β_d	β_d (SF)	β_c/β_d	β_{hs} (1)	β_{ec}	β_{ed}	β_{ed} (SF)	β_{ed} (codes)	CM(2) (dB)	MPR (dB)	AG(4) Index	E-TFCI
1	11/15(3)	15/15(3)	64	11/15(3)	22/15	209/225	1039/225	4	1	1.0	0.0	20	75
2	6/15	15/15	64	6/15	12/15	12/15	94/75	4	1	3.0	2.0	12	67
3	15/15	9/15	64	15/9	30/15	30/15	β_{ed1}: 47/15 β_{ed2}: 47/15	4	2	2.0	1.0	15	92
4	2/15	15/15	64	2/15	4/15	2/15	56/75	4	1	3.0	2.0	17	71
5	15/15(4)	15/15(4)	64	15/15(4)	30/15	24/15	134/15	4	1	1.0	0.0	21	81

Note 1: Δ_{ACK}, Δ_{NACK} and $\Delta_{CQI} = 8 \Leftrightarrow A_{hs} = \beta_{hs}/\beta_c = 30/15 \Leftrightarrow \beta_{hs} = 30/15 * \beta_c$.

Note 2: CM = 1 for β_c/β_d =12/15, β_{hs}/β_c=24/15. For all other combinations of DPDCH, DPCCH, HS- DPCCH, E-DPDCH and E-DPCCH the MPR is based on the relative CM difference.

Note 3: For subtest 1 the β_c/β_d ratio of 11/15 for the TFC during the measurement period (TF1, TF0) is achieved by setting the signaled gain factors for the reference TFC (TF1, TF1) to β_c = 10/15 and β_d = 15/15.

Note 4: For subtest 5 the β_c/β_d ratio of 15/15 for the TFC during the measurement period (TF1, TF0) is achieved by setting the signaled gain factors for the reference TFC (TF1, TF1) to β_c = 14/15 and β_d = 15/15.

Note 5: Testing UE using E-DPDCH Physical Layer category 1 Sub-test 3 is not required according to TS 25.306 Table 5.1g.

Note 6: β_{ed} can not be set directly; it is set by Absolute Grant Value.

SAR Evaluation Considerations

for

Laptop computers

with

Antennas Built-in on Display Screens

Initial Proposal

Purpose

- to address RF exposure evaluation requirements
  - for simultaneous transmission from multiple antennas deployed on full-size laptop computer display screens
    - WWAN (3G), WLAN (802.11), Bluetooth etc.
    - operating at various frequency, power, antenna-to-antenna and antenna-to-user separation distances
- to streamline approval & test requirements for simultaneous transmitting antennas with medium to low exposure potentials – laptop displays
  - to streamline test requirements by reducing redundant and unnecessary tests according to device operating and exposure characteristics
  - to streamline administrative and permissive change requirements

Issues

- SAR test procedures published by the IEEE & IEC are for handsets only
  - inappropriate for testing laptop and similar devices
  - procedures do not address simultaneous transmission
  - procedures are also obsolete for testing many digital modulations – 3G, Wi-Fi, Wi-Max etc.
- exposure potentials for laptop display antennas are typically low, but exposure conditions can be complex and test procedures are unavailable
  - these cannot be approved by TCB when procedures are unavailable

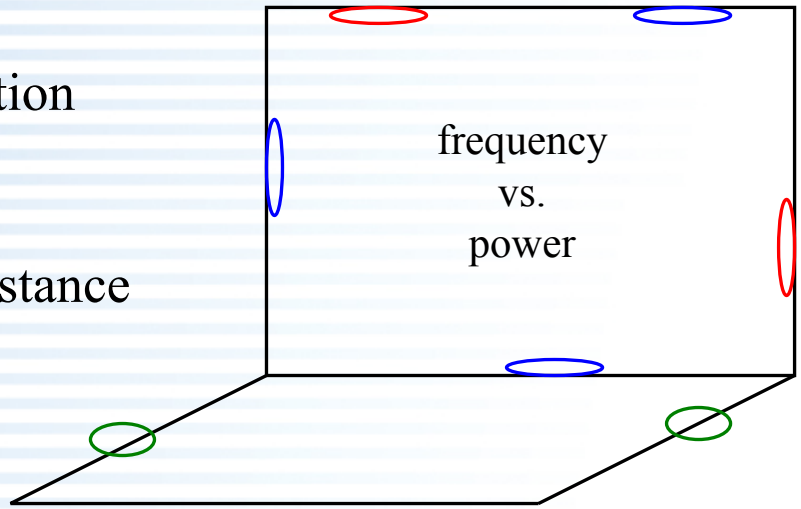
Current Status

- specific and uniform test procedures for various multiple antenna configurations for laptop computers and other products are mostly unclear and unavailable
  - TCB approval is limited due to lack of procedures for simultaneous transmitters
    - restrictions usually apply to individually approved modules and transmitters
- simultaneous transmission substantially complicates issues
  - mixed mobile and portable exposure conditions in the same host device
  - mixed frequency, power and distance considerations
  - definition and test requirements are generally unclear
- transmitter modules are intended for multiple host devices (laptops) but such flexibility is substantially limited due to lack of acceptable procedures
  - OEM may need to address issues through subsequent filings
  - responsible party and permissive change requirements become complex
- laptops use both licensed and licensed transmitters
  - uniform test procedures on RF exposure evaluation for both licensed and unlicensed transmitters in the same host device are unavailable

Example

mobile = MPE

antenna separation
distances
vs.
user separation distance



portable = SAR

user installation
vs.
OEM integration

exposure potential vs. test requirements

Test Reduction Procedures

- according to TCB low power threshold
  - tests are not required when power is $\leq 60/f_{(GHz)}$
  - need frequency, power & distance criteria when above 60/f
    - test on highest output channel when $\geq (5 + \frac{1}{2} \cdot n)$ cm from users & nearby persons; where $n = P/(60/f) - 1$
      - n relates separation distance to both frequency and power
    - require simultaneous transmission evaluation only when
      - antenna-to-antenna distance $< (5 + \frac{1}{2} \cdot n_x + \frac{1}{2} \cdot n_y)$ or
      - antenna-to-user distance $< (5 + \frac{1}{2} \cdot n_x)$
      - where $n = P/(60/f) - 1$
    - simultaneous transmission evaluation is not required
      - when output $\leq 60/f$ and either user-antenna or antenna-antenna distance is ≥ 5 cm
      - $\sum(SAR_{1\text{-}g})$ of simultaneous transmitting antennas < SAR limit
- need to review/revise administrative policies and procedures to avoid inconsistencies before implementing these concepts

Other Flexibilities

- increase grantee and OEM flexibility to integrate modules
  - grant covers identical transmitter & antenna configurations using the same laptop display
  - permissive change required only when changes in laptop construction are within 5 cm of any antenna
  - antenna locations may shift by ± 1 cm
    - when antenna-to-antenna & antenna-to-user separation distances are the same or larger
    - require permissive change only when original SAR is > 75% of the SAR limit
- addressing exposure concerns to gain modular flexibility
  - the simultaneous transmission procedures also take into account other antennas in the keyboard and antennas at > 20 cm from users
  - apply default separation distances to reduce unnecessary tests
- permissive change rules and grantee responsibility remain unchanged
  - the added flexibilities reduce subsequent filings for defined changes

Threshold Calculations

Output Power P (mW)		835	1900	2450	5200	5800
½ · n		(MHz)				
0		≤ 143	≤ 63	≤ 48	≤ 23	≤ 20
1		144	64	49	24	21
2	cm	288	127	98	47	42
3		432	190	147	70	63
4		575	253	196	93	83
5		719	316	245	116	104

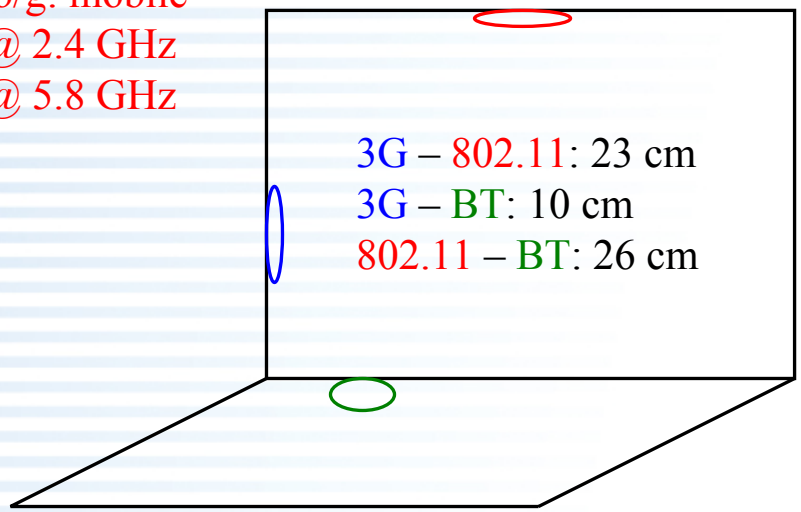
n = P/(60/f)-1; P is rounded to the nearest mW and (½ · n) is rounded to the nearest cm
Antenna-to-antenna distance = $(5 + ½\cdot n_x + ½\cdot n_y)$ cm. Antenna-to-user distance = $(5 + ½\cdot n)$ cm

Hypothetical Example

802.11 a/b/g: mobile
50 mW @ 2.4 GHz
25 mW @ 5.8 GHz

1900 MHz: portable
255 mW 3G
10 cm from base

3 mW Bluetooth
1.5 cm from base



<u>independent transmission</u>

output > 60/f & antenna-user: $(5 + \frac{1}{2} \cdot n)$
- 3G → 9 cm: highest output channel only
- 802.11 b/g → 6 cm: mobile
- 802.11 a → 6 cm: mobile

output ≤ 60/f: user distance & SAR does not apply

<u>simultaneous transmission</u>

output > 60/f & antenna-antenna: $(5 + \frac{1}{2} \cdot n_x + \frac{1}{2} \cdot n_y)$
- 3G & 802.11 b/g → 10 cm: 23 cm > 10 cm
- 3G & 802.11 a → 10 cm: 23 cm > 10 cm
- 3G & Bluetooth → 9 cm: 10 cm > 9 cm
- 802.11 a/b/g & Bluetooth → 6 cm (mobile & no SAR)

output ≤ 60/f: no SAR when antenna/user ≥ 5 cm
- Bluetooth: no simultaneous transmission SAR

Expanding the Concepts

- laptop procedures are based on multiples of 60/f
  - with frequency, power, distance and simultaneous transmission considered for laptop display exposure conditions only
- require SAR based frequency, power and distance criteria for the broader and more generic situations
  - need other exposure and planar tissue models to establish conservative SAR criteria
  - may consider using resonant dipoles at various antenna-to-tissue distances to establish conservative exposure conditions to account for external conditions – propagation, matching, scattering etc.
  - need to relate SAR, power and distance to mobile exclusions at 20 cm to maintain continuity between SAR & MPE limits
- need to consider SAR based criteria for all transmitters & modules
  - for both licensed and unlicensed, independent of the Part 15 modular approval requirements, to address simultaneous transmission
  - need SAR based criteria for simultaneous transmission test procedures

Future Considerations

- laptop computer procedures have taken frequency, power and distance into consideration
  - based on the operating configurations and exposure conditions expected for laptop computers only
  - however, it is not SAR based and may not apply to other situations
- extending the laptop concepts
  - the laptop procedures facilitate taking the concepts to the next step
    - to develop SAR based frequency, power and distance criteria
    - identifies the need to apply the same exposure procedures for both licensed and unlicensed transmitters & modules
    - allow critical issues, such as simultaneous transmission and other transmitter testing issues, to be addressed through test procedures
    - to ease bottlenecks for other test requirements that are needed by industry and TCB
- next steps
  - invite comments; review initial applications; consider Permit But Ask etc