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

Submission Title: [Radio Specification Analysis of Draft FSK PHY]
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Re: []

Abstract: []

Purpose: [To assist with the definition of the 15.4k FSK PHY]

- Operating Frequency Range and Channel Parameters
  - Sub-GHz PHYs

PHY (MHz)	BAND (MHz)	REGION	BIT RATE (kb/s)	MOD. INDEX	CH. SPACING (kHz)	MOD. BW (kHz)
470	470 - 510	PRC	37.5	0.5	200	56.25
			25	1.0	200	50
			12.5	4.0	200	62.5
780	779 - 787	PRC	37.5	0.5	200	56.25
			25	1.0	200	50
			12.5	4.0	200	62.5
863	863 - 870	EU / CEPT	25	1.0	100	50
			12.5	4.0	100	62.5
915	902 - 928	N.A.	37.5	0.5	200	56.25
			25	1.0	200	50
			12.5	4.0	200	62.5
917	917 – 923.5	KR	37.5	0.5	200	56.25
			25	1.0	200	50
			12.5	4.0	200	62.5
920	920 – 928	JP	37.5	0.5	200	56.25
			25	1.0	200	50
			12.5	4.0	200	62.5

Operating Frequency Range and Channel Parameters

- 2.4 GHz PHY

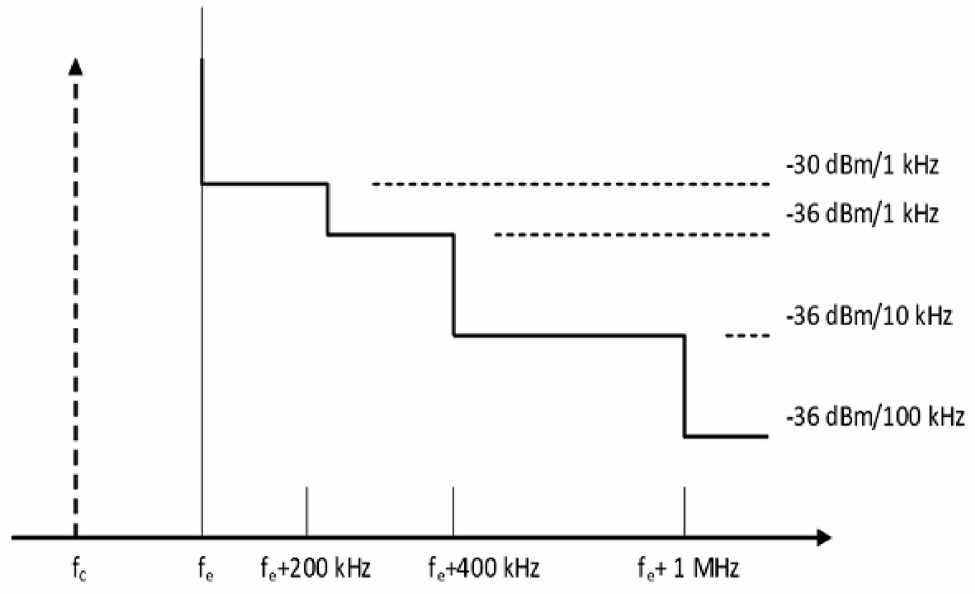
PHY (MHz)	BAND (MHz)	REGION	BIT RATE (kb/s)	MOD. INDEX	CH. SPACING (kHz)	MOD. BW (kHz)
2450	2400 – 2483.5	WW	37.5	0.5	200	56.25
			25	1.0	200	50
			12.5	4.0	200	62.5

- 200 kHz uniform channel spacing except EU / CEPT (100 kHz)
  - Compliance with current ETSI regulations for FHSS
  - Note: Disparity between Table 6 of EN 300 200-1 v2.3.1 and Annex 1g of ERC 70-03
- 37.5 kb/s NOT supported EU / CEPT
- Lowest BR has widest modulation BW
- 200 kHz channel spacing at 2450 MHz (83 MHz) – best use of spectrum mandating NB PHY in WB spectrum?
  - Take full advantage of FSK spreading factor processing gain?

- FSK PHY RF Requirements
- Radio Frequency Tolerance
  - ±20 ppm for all sub-GHz bands
    - Worst case nominal frequency offset is ±18.56 kHz (37% of FSK PHY minimum mod. BW)
  - ±40 ppm for 2450 MHz band
    - Worst case nominal frequency offset is ±96 kHz (192% of FSK PHY minimum mod. BW)
    - Best use of spectrum?
- Channel Switch Time
  - Channel switch time shall be less than or equal to 500 μs. The channel switch time is defined as the time elapsed when changing to a new channel, including any required settling time.
    - Definition for PHY constant for LECIM aTurnaroundTime?
    - Baseline Standard = 12 symbols (15.4g = 1 ms)
    - At the lowest PHY data rate 12 symbols = 960 μs aTurnaroundTime will influence minimum number preamble octets

- Transmit spectral mask
  - The transmit spectral content shall conform to all local regulations
    - 200 kHz channel spacing15.4g CSM (50 kb/s Mod. Index = 1.0 -> modulation BW = 100 kHz) can comply to regulatory requirements if Gaussian filtering applied to TX data
    - Infers compliance for 15.4k FSK PHYs in 200 kHz channel spacing
    - Compliance with regulatory requirements for 100 kHz channel spacing for EU / CEPT regulatory requirements?
      - ETSI EN 300 220-1 v2.3.1
      - ERC 70-03 (Edition Sept. 2011)

- Transmit spectral mask
  - For the purposes of objectivity the test spectra were generated by a Rhode & Schwarz SMIQ VSG and laboratory amplifier set to output an indicated power level of +14 dBm (~25 mW erp)
  - ETSI EN 300 220-1 v2.3.1Modulation BW limits:
    - Test method is consistent with the ETSI standard



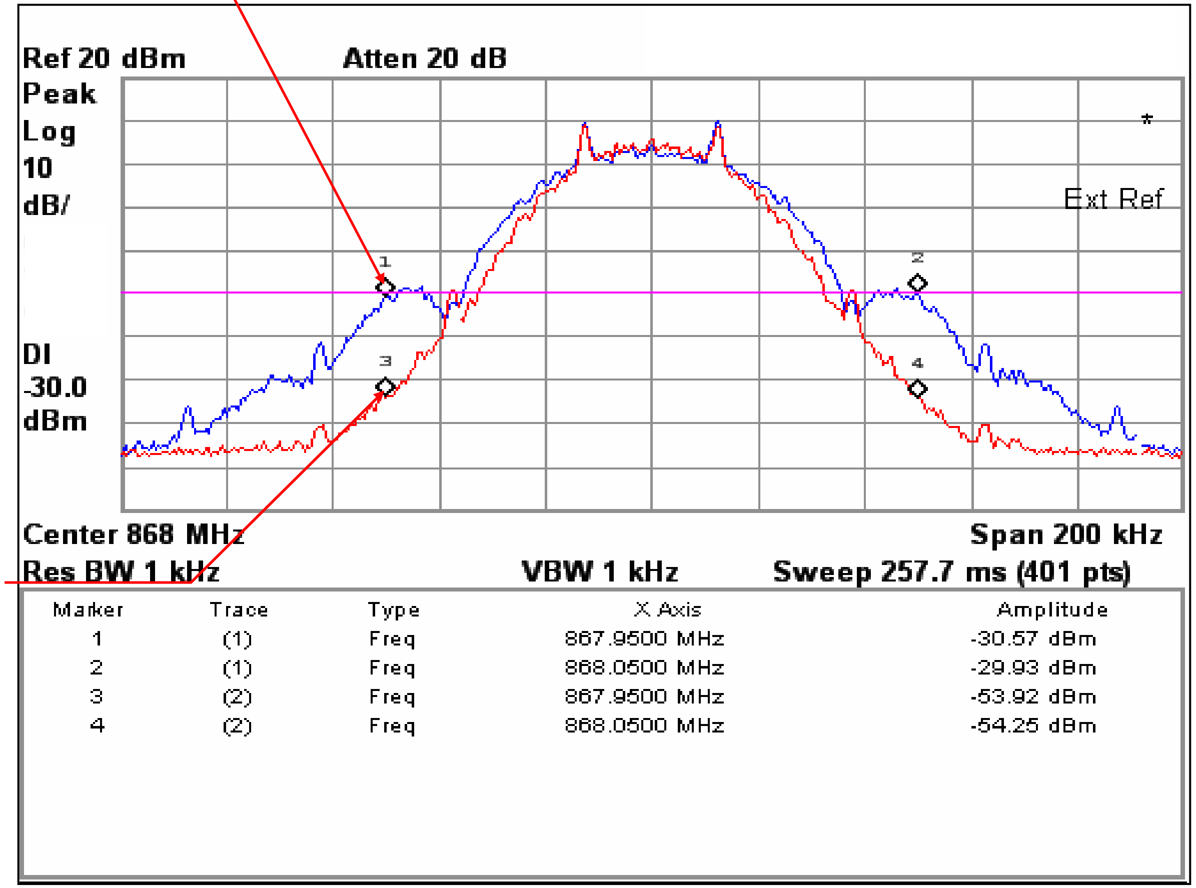
NOTE:

- f_c is the emission center frequency.
- f_e is the sub-band edge frequency.
- Only the upper half of the emission is shown. The lower half is a mirror image.

- Transmit spectral mask
  - ETSI EN 300 220-1 v2.3.1Modulation BW limits
  - Lower and Upper Frequency Point Definition
    - The difference between the two frequencies f_a and f_b obtained with resolution bandwidth 1 kHz and level 1 uW is the modulation bandwidth
    - For FHSS systems the maximum permissible modulation bandwidth is 100 kHz (mandated by 100 kHz channel spacing)
    - For “non-specific” modulation, modulation bandwidths up to 300 kHz is allowed
    - Where the band is divided into sub-bands the limits shall apply to the sub-band edge frequencies. In the table below $f_{e,lower}$ and $f_{e,upper}$ are the lower and upper edges of the band in which the equipment operates
    - Sub-band edge may be assumed to imply channel band edge for channelized systems
  - Further information refer to 15-11-0789-00-004g

- Transmit spectral mask
- 25 kb/s M.I. = 1.0

GFSK BT = 1.0
MKR 1, MKR 2 indicate nom. Mod BW limits for 100 kHz channel spacing
MARGINAL COMPLIANCE

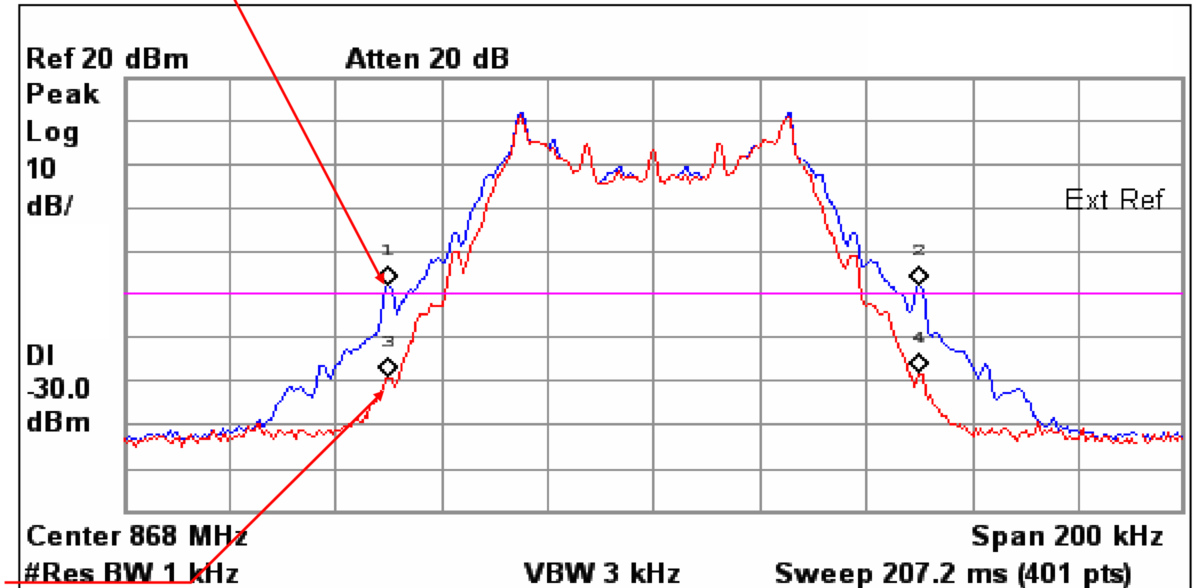


GFSK BT = 0.5
MKR 3, MKR 4 indicate compliance with ~20 dB margin

- Transmit spectral mask
- 12.5 kb/s M.I. = 4.0

GFSK BT = 1.0
MKR 1, MKR 2 indicate nom. Mod BW limits for 100 kHz channel spacing
MARGINAL COMPLIANCE

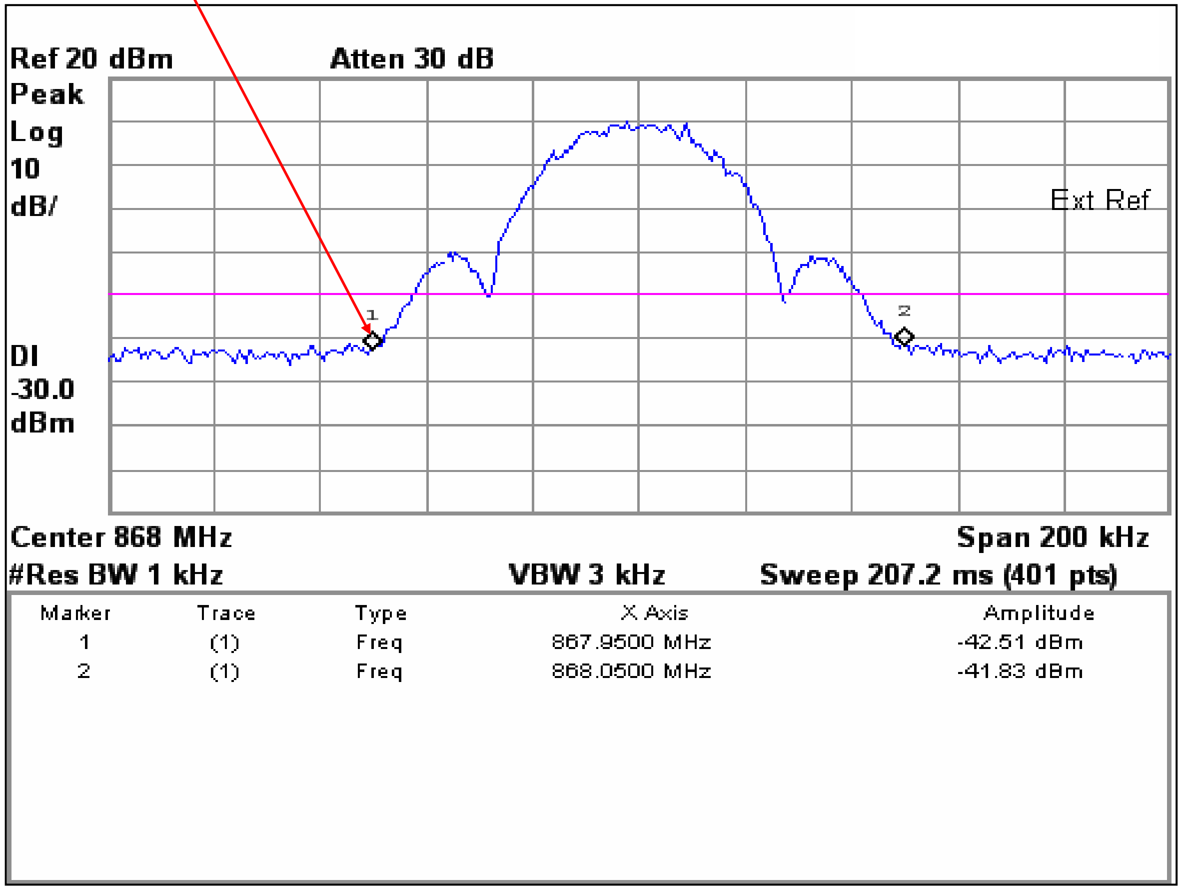
GFSK BT = 0.5
MKR 3, MKR 4 indicate compliance with ~20 dB margin



Marker	Trace	Type	X Axis	Amplitude
1	(1)	Freq	867.9500 MHz	-27.76 dBm
2	(1)	Freq	868.0500 MHz	-27.95 dBm
3	(2)	Freq	867.9500 MHz	-49.15 dBm
4	(2)	Freq	868.0500 MHz	-48.18 dBm

- Transmit spectral mask
- 37.5 kb/s M.I. = 0.5 (Silicon source)

GFSK BT = 1.0
MKR 1, MKR 2 indicate ~10 dB margin!



- Transmit spectral mask
  - For 100 kHz / FHSS in Europe GFSK BT = 0.5 required
    - Increases system requirements on to receiver
  - Define non-specific modulation case to allow mod. BW up to 300 kHz and implement frequency agility (AFA + LBT)
    - “Grey” area as to whether you can still define 100 kHz channel spacing
    - No consistent response based on Notified Body “interpretation”
  - Standardize on 200 kHz channel spacing for sub-GHz FSK PHY channel spacing
    - 15.4g MR-FSK CSM
      - Define non-specific modulation case to allow mod. BW up to 300 kHz and implement frequency agility (AFA + LBT)
    - ETSI TG 28 looking at smart grid utilization in Europe and are taking reference from 15.4g FSK PHY proposals. Would fit some LECIM applications
  - Define PHY more suitable for 100 kHz / FHSS operation
    - e.g. GFSK 12.5 kb/s, Mod. Index = 2.0, BT = 1.0

- Transmit Power
  - The maximum transmit power is limited by local regulatory bodies
  - The transmitter shall also support system operation with a link budget including at least 120 dB of path loss
  - Note: 863 – 870 MHz maximum permitted output power for systems with a modulation bandwidth up to 300 kHz is 25 mW erp (+14 dBm)
  - Note: In Japanese 920 – 928 MHz band maximum power in the band 923.5 – 928.1 MHz is 20 mW erp (+13 dBm)
    - Remember - The transmitter shall also support system operation with a link budget including at least 120 dB of path loss

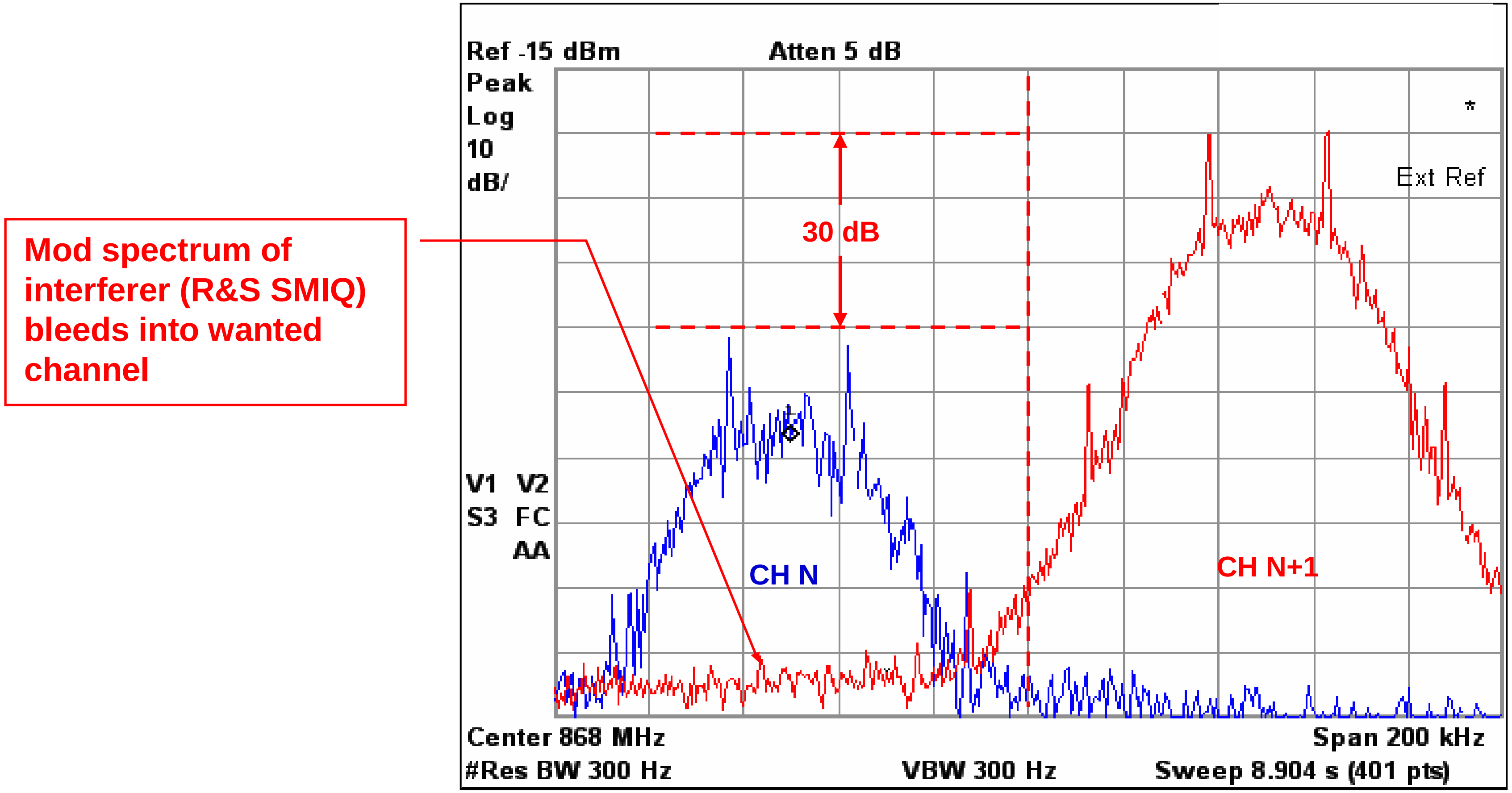
- Receiver sensitivity
  - Currently defined as -85 dBm or better. Bit rate not defined
  - The baseline standard defines sensitivity as the 1% PER for a PSDU length of 20 octets
  - Maximum permitted output power in Korea Band is +10 dBm
    - Implies minimum RX sensitivity of -110 dBm which may require FEC or “spreading” processing / circuitry
    - Processing gain provided by FEC? (15.4g = 6 dB)
    - Spreading? Symbol rate is DIVIDED by SF – very low OTA rate
  - Assuming above define minimum uncoded sensitivity of -104 dBm at 12.5 kb/s.
  - $S = [S_0 + 10*\log(R/R_0)]$ dBm
    - S_0 = -100 for uncoded / non-spread data
    - R_0 = 12.5 kb/s
    - R = bit rate in kb/s

- Receiver interference rejection

ADJACENT CHANNEL REJECTION	ALTERNATE CHANNEL REJECTION
35 dB	50 dB

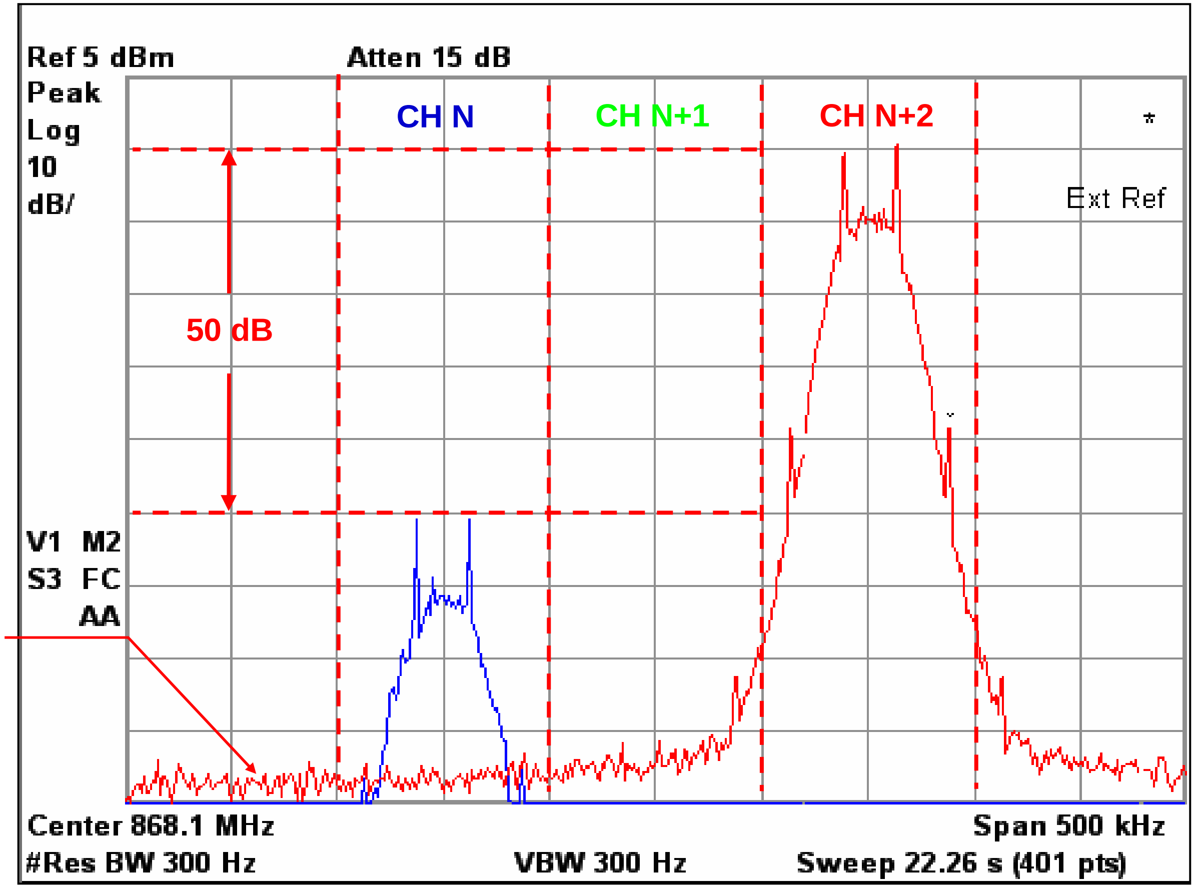
- ACR and AACR are linear interferer mechanisms and on modern RX architecture ACR is limited by
  - Filter BW characteristics
  - Phase noise
- In a 200 kHz channelized system the N±1 channel (ACR) is the N±2 channel (AACR) of 100kHz channelized system
  - Device meeting ACR requirement at 200 kHz may not meet AACR for a 100 kHz channelized system, even though RX channel filter is identical
- Minimum RX interference rejection requirements are challenging for 100 kHz channel spaced systems
  - 50 dB approaching blocking specification figure

- Receiver interference rejection
  - Consider the case of 25 kb/s PHY (GFSK BT = 0.5) with a modulated interferer in the adjacent channel



- Receiver interference rejection
  - Consider the case of 25 kb/s PHY (GFSK BT = 0.5) with a modulated interferer in the alternate channel

Phase noise of interferer (R&S SMIQ) bleeds into wanted channel



- Receiver interference rejection
  - ACR / AACR degradation in 100 kHz channelized system as a function of interfering source phase noise (25 kb/s, M=1.0, GFSK BT = 0.5)

INTERFERER SOURCE	ADJACENT CHANNEL REJECTION	ALTERNATE CHANNEL REJECTION
R&S SMIQ VSG	37 dB	42 dB
SILICON	32 dB	41 dB

    - PHASE NOISE of interferer impacts on RX interference rejection
  - For a mixed PHY can we quote a single value for ACR and AACR INDEPENDENT of PHY?
    - Specify unmodulated carrier (16.1.5.8 15.4g)
  - ACR / AACR degradation for modulated / unmodulated carrier in 200 kHz channelized system:

INTERFERER SOURCE	ADJACENT CHANNEL REJECTION	ALTERNATE CHANNEL REJECTION
UNMODULATED CARRIER	42 dB	50 dB
MODULATED CARRIER	41 dB	49 dB

    - NEGLIGABLE difference between modulated / unmodulated cases
    - Can specify UNMODULATED carrier

- Receiver interference rejection
  - Propose more realizable ACR / AACR values representative of current generation silicon:

CHANNEL SPACING	ADJACENT CHANNEL REJECTION	ALTERNATE CHANNEL REJECTION
100 kHz	25 dB	35 dB
200 kHz	30 dB	45 dB

  - Alternatively:
    - For mixed environment operation (license-exempt frequency space) consider for interference rejection for non-linear interfering mechanisms – Blocking specification

BLOCKER	REJECTION
1 MHz	50 dB
5 MHz	60 dB

    - Consider co-channel rejection (CCR) as a figure-of-merit for linear interference rejection

CO-CHANNEL REJECTION
-10 dB

- SFD Length
  - Refer to 15-11-0877-00-00k (Oh, Choi, Park) and 15-12-0030-00-004k (Seibert, Kent, Rolfe) for simulation of false alarm rate for 2 and 4 octet SFDs
  - Practical case of RX detecting 2 octet SFD in mixed signal environment (902 – 928 MHz ISM band). Use 15.4g SFD as example
  - “False” detection occurs every few seconds (up to 18 times / 100 second period)
    - Channel conditions / Background spectrum dependent
  - 3-octet SFD reduces false detection to << 1 in 500 second period (as a rule of thumb, false detection period doubles for each additional bit of “pattern” to be detected

- SFD Length
  - 3-octet SFD reduces false detection – increases time between false detections
  - Most transceivers have some form of preamble (0x55 / 0xAA) detect flag or a sync address that can be configured for preamble / SFD
  - In conjunction with SFD have false detection rate similar to above
- Conclude that 2-octet SFD should prove sufficient to prevent significant false detection rate in conjunction with preamble detect
  - Benefit of 3-octet SFD with 1/3 less overhead

- Clear Channel Assessment (CCA)
  - Ensure CCA mechanism complies with European LBT requirements