AWS-3 Band Interference Analysis

December 12, 2007

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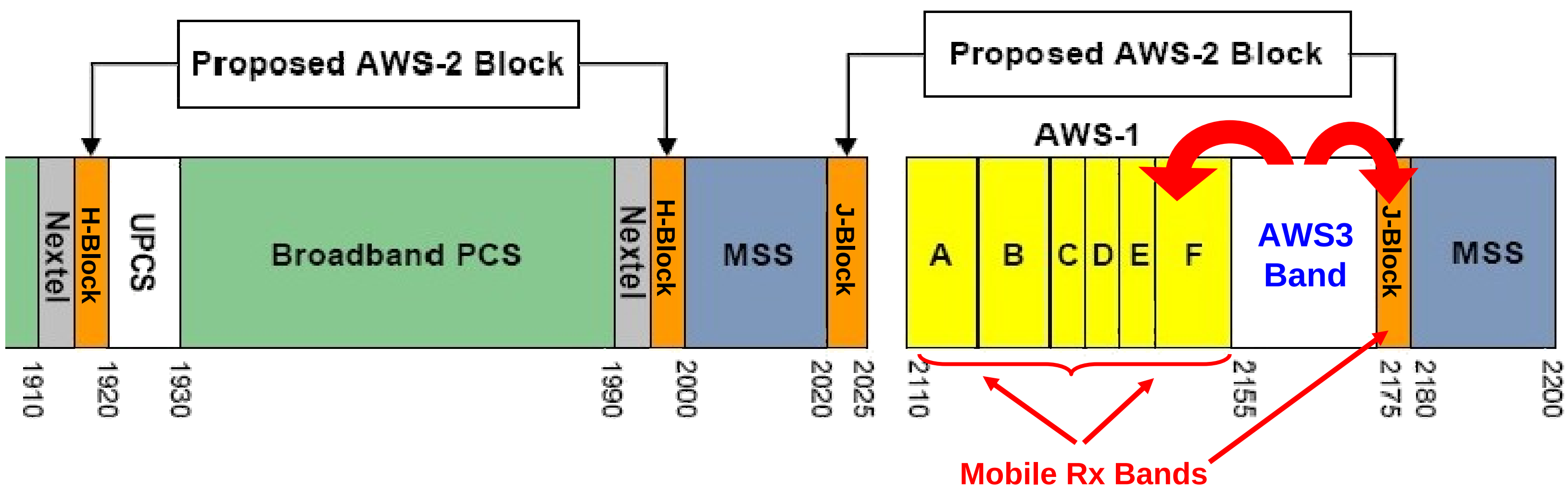
Introduction & Background

- Purpose: to study the potential interference from AWS-3 band uplink transmissions to adjacent AWS-1 and AWS-2 mobile receive bands
  - See spectrum allocation diagram below
  - Analyze mobile-to-mobile interference for Receiver Overload & OOBE
- Analyze test results from H-Block proceeding and new tests conducted by Motorola using a prototype AWS-1 device to determine uplink power limits required for AWS-3 band to protect AWS-1 & AWS-2
  - Include CTIA's tests & Motorola's tests submitted in the H-Block proceeding
  - Use typical minimum separation distances & path losses between users for analysis
- Analyze practical filter design issues
  - Include data submitted by Avago & Motorola in this proceeding



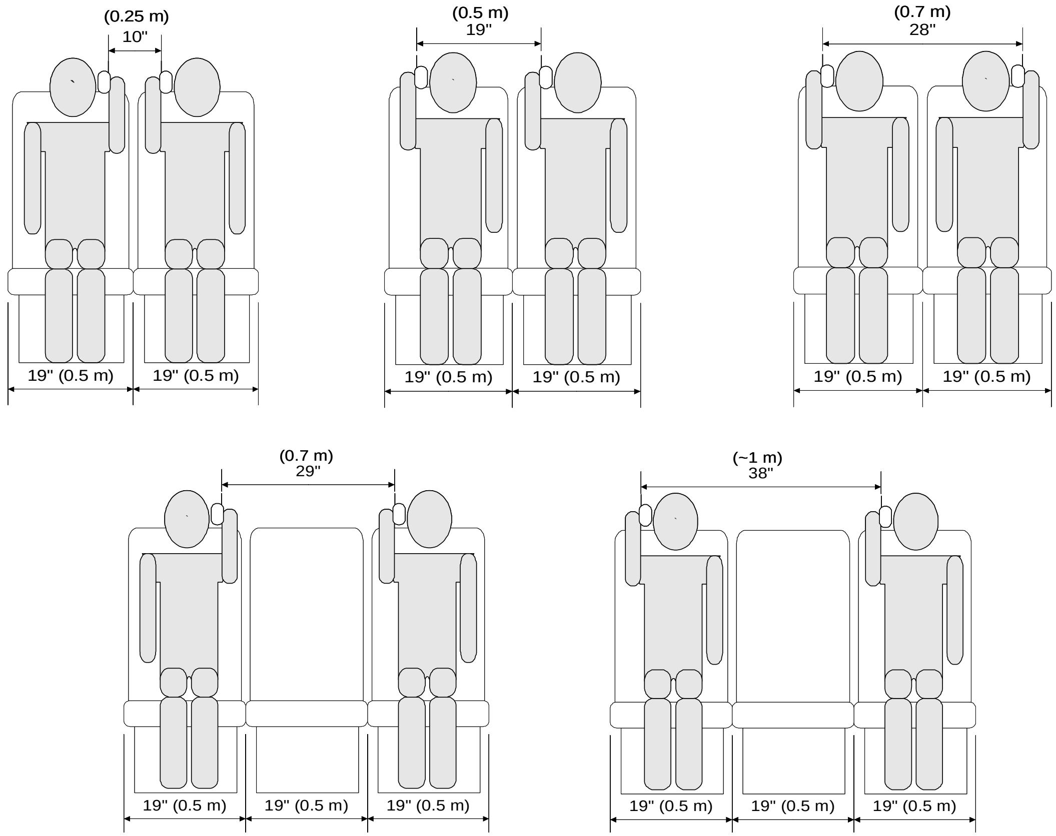
Introduction & Background (Cont')

- Mobile-to-mobile interference only impacts AWS-3 into AWS-1 & AWS-2. It would not impact AWS-3 mobile receivers.
- Types of mobile-to-mobile interference include:
  - ***Receiver Overload (a.k.a. Adjacent Channel Interference):*** Interference resulting from victim receiver's selectivity or ability to reject strong adjacent band signals. Typically, CMRS devices utilize a receive filter to attenuate signals from other (undesired) bands.
  - ***Out-of-Band-Emissions (OOBE):*** Interference from RF splatter of transmitters into adjacent bands, which can be received on a co-channel basis by victim receivers operating in adjacent bands. This cannot be mitigated by the receive filter because the OOBE interference is co-channel. OOBE must be reduced at the transmitter with a combination of emission mask and transmit filtering to attenuate emissions into the adjacent bands.
  - ***Intermodulation (IM):*** Interference due to interfering signals produced inside the victim receiver resulting from the combination of a strong adjacent signal with a device's transmit frequency. This is not a problem with AWS-3 interference into the AWS-1 or AWS-2 bands.
- Mobile-to-mobile interference can be mitigated by physical separation of the mobile devices and the use of RF filters.

Minimum Separation Distance Between Users

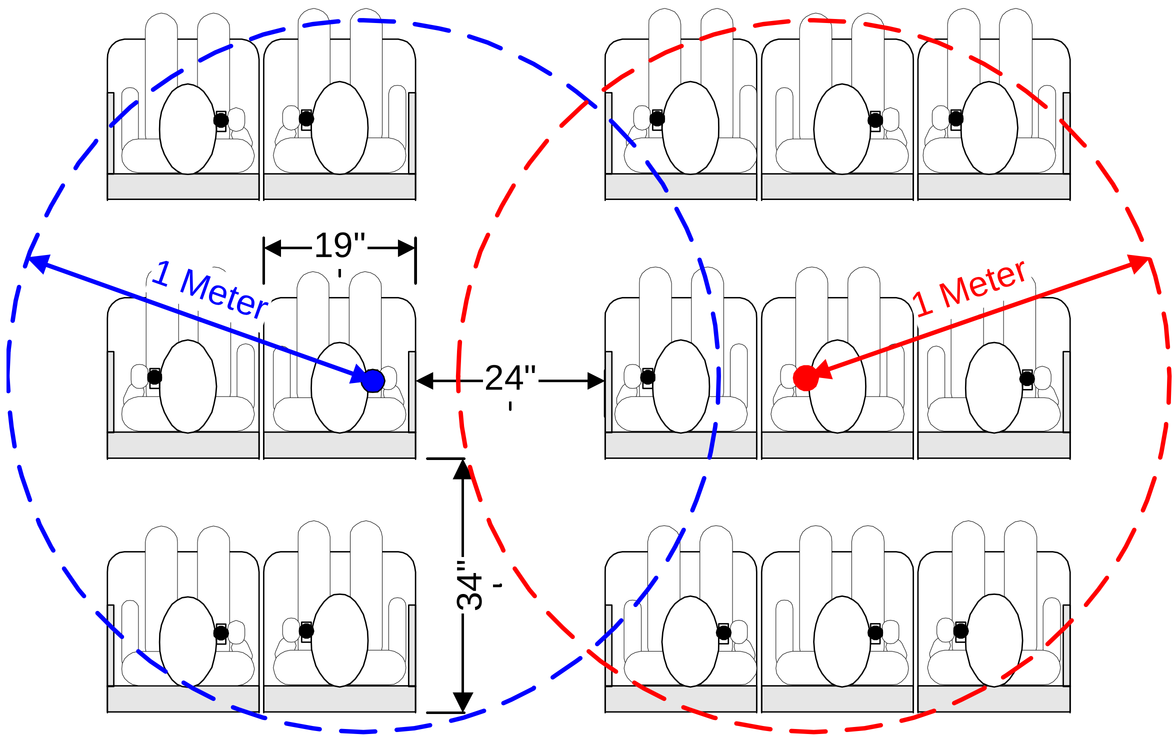
- The minimum required separation distance is used with the test results to determine AWS-3 band OOBE and transmit power levels required to prevent interference to AWS-1 and AWS-2 bands.
- Minimum separation distance of 1 meter is used to avoid harmful interference between 2 or more devices operating in close proximity.
  - There are many situations where the separation distance between CMRS users in close proximity will be less than 1 meter. (See diagrams on pages 6-7)
  - In addition, the "1 meter separation" distance can include many CMRS users (see diagram on page 7), resulting in additive interference from each of these users. Our analysis did not consider interference from multiple transmitters.
- We assume 3 dB of additional loss to account for head and body losses and other factors.
- For the 2.1 GHz AWS band, the total losses over a one meter distance would be 42 dB (39 dB of free-space path loss + 3 dB of additional losses).
  - This path loss is used in the interference analyses to determine appropriate mobile OOBE and power limits for the AWS-3 band.

Typical Separation Distances Between Users



CMRS devices are used in a variety of locations when people are within close proximity. This includes inside buildings & vehicles. In-building locations include: conference rooms, offices, train stations, airport terminals, stadiums, arenas, doctor's waiting rooms, restaurant lobbies, and bus stations. In-vehicle locations include inside trains, buses, airplanes on the ground, and automobiles. The diagram above uses the average seat width of 0.5 meters (19 to 20 inches). Airplane seats will be closer at about 17 inches apart. Commuter & regional train seats are about 18-19 inches apart. These cases demonstrate a user device separation of 0.25 to 1 meter.

One Meter Separation Distance -- Includes Multiple CMRS Users (up to 9 simultaneous users)



The above diagram is drawn to scale with CMRS devices and users. It uses the average seat width of 0.5 meters (19 to 20 inches). Airplane seats will be closer at about 17 inches apart. Commuter & regional train seats are about 18-19 inches apart. These cases include up to 9 device users within the a 1 meter distance, with some devices 0.5 meters apart. With multiple device transmitters, the OOBE and adjacent channel interference received at victim devices will be worse, as compared to the case with only 1 transmitting device.

Practical Filter Design Issues

- Interference can be mitigated through a combination of transmit and receiver filters.
- However, adequate guard band must be provided between transmit and receive bands. The amount of guard band is affected by:
  - ❖ *Filter Slope:* The transition from pass band to reject band is affected by operating frequency and bandwidth.
  - ❖ *Temperature Motion:* The pass band of the filter shifts with temperature changes; designed for range of -30ºC to +85ºC.
  - ❖ *Consistency:* Pass band will vary from one device to the next with variations in the manufacturing process
- Assumptions about filter design and its effect on interference mitigation are based on filter information provided by Avago Technologies (formerly Agilent).
- We assume use of FBAR filters – a premium RF filter that provides better rejection performance than other filters (e.g., SAW filters).
- To account for the expected slope, temperature motion, and consistency, Avago concludes that 12.5 to 13 MHz of guard band is required to separate the AWS-3 and AWS-1 bands.

Practical Filter Design Issues

- Importantly, Avago notes that filters are typically designed to pass multiple bands to provide greater utility across various markets.
  - AWS-1 filters are being designed to cover the entire 2110-2170 MHz band to accommodate UMTS Band IV (2110-2155 MHz) in the U.S. and UMTS Band X (2110-2170 MHz) in South America.
  - The 2110-2170 MHz band is also designated as UMTS Band I in European and Asian markets.
- This is confirmed by the information provided by Avago, which shows that the AWS-3 band is entirely within the pass band of the AWS-1 receive filter with no more than 1.5 dB of attenuation across the entire band.
- The filter used in Motorola's tested AWS device shows similar rejection.
- With the licensing of AWS-2 spectrum, we can expect filter manufacturers to design filters across the entire 2110-2180 MHz band.
- As a result, the filters that are actually produced for use in AWS-1 devices can be expected to provide less rejection of the AWS-3 band, and will be more susceptible to receiver overload interference from AWS-3 mobile transmissions, than the optimized AWS-1 filter used in Avago's analysis.

Review of H-Block Tests

- Mobile-to-mobile interference tests were conducted and submitted to the FCC to show the impact to mobiles operating in the PCS receive band (1930-1990 MHz) from mobiles transmitting in the H-Block (1915-1920 MHz); see e.g., CTIA and Motorola filings.
- For these tests, the interfering band was separated from the victim receive band by 10 MHz of guard band spectrum.
- Tests were conducted for CDMA, GSM and UMTS receivers, and CDMA and GSM interferers in the H-Block on standard channel assignments within the bands.
- Tests were conducted with interferers operating in various parts of the H-Block spectrum, including the upper (1918-1920 MHz), middle (1917-1918 MHz), and lower (1915-1917 MHz) segments, and the victim receiver in the lower part of the PCS spectrum (at 1930 MHz).

H-Block Test Procedures

CTIA Tests

- CTIA developed an H-Block test plan and commissioned two independent test labs to perform testing (PCTEST & WINLAB)
- A variety of devices were tested (GSM, CDMA, and UMTS)
- Real-world conditions were taken into account
  - Typical operating & noise levels for indoor environments
  - Representing signal fading conditions (tested to operating levels of -105 dBm for CDMA & UMTS and -102 dBm for GSM)
- Devices were tested at room temperature and at 100^{o}F
- Tests for Receiver Overload, IM, AWGN, and OOBE were included
- For more information, see "*Comments of CTIA*," filed with the FCC in WT Docket No. 04-356 on Dec. 8, 2004

H-Block Test Procedures

Motorola Tests

- Motorola performed Receiver Overload tests using CDMA and GSM handsets
- Tests measured performance degradation for 1 and 3 dB desense thresholds, using standard error rates
  - GSM handset measured sensitivity at -109 dBm
- Tests used operating levels of -106 and -108 dBm for GSM handsets
  - These levels more closely represent faded signal conditions as compared to CTIA tests, which used -102 dBm for GSM (reference sensitivity) and -105 dBm for CDMA & UMTS

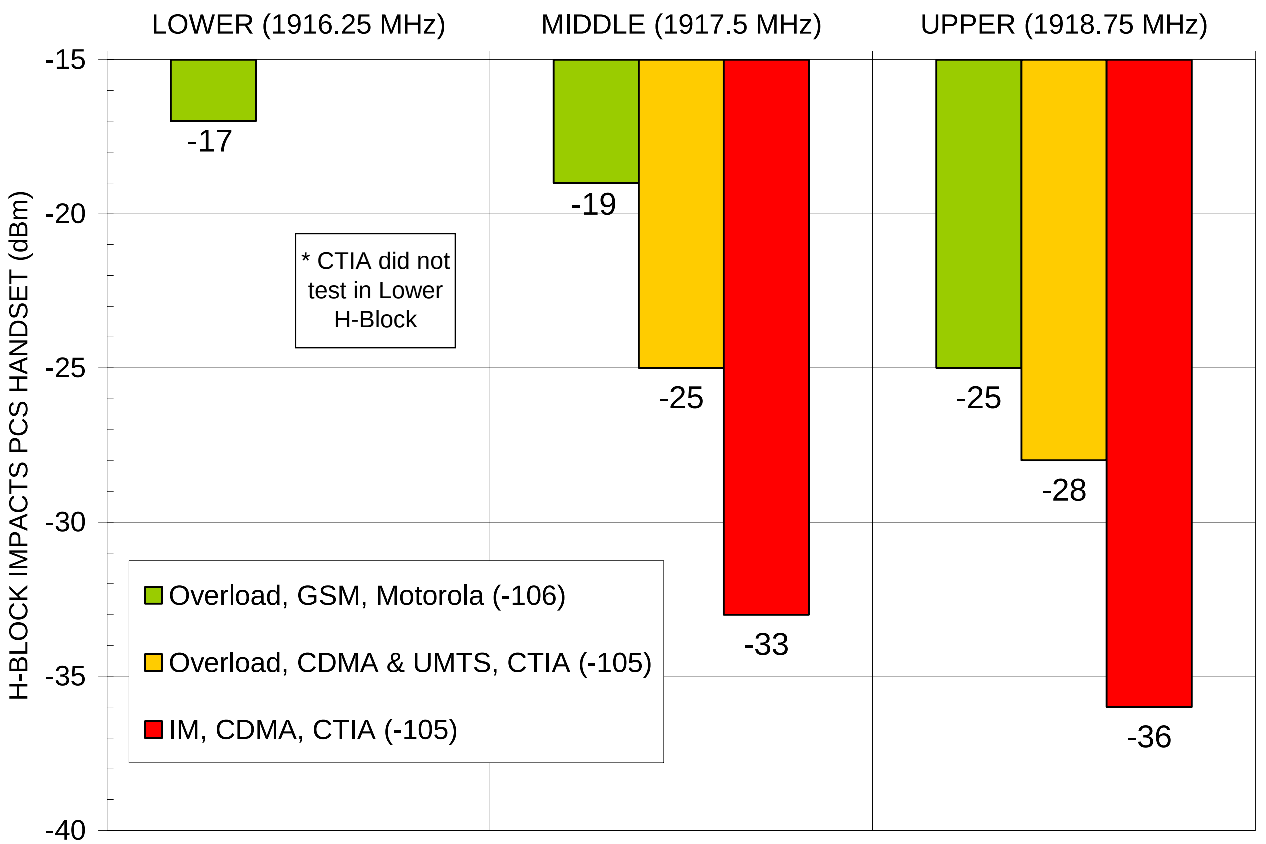
  Note: To evaluate for equivalent operating level and protection for both, use -106 dBm for GSM (Motorola) and -105 dBm for CDMA (CTIA)
- Devices were tested at room temperature with no environmental noise added
- For more information, see "*Ex Parte Letter of Motorola*," filed with the FCC in WT Docket No. 04-356 on Aug. 24, 2005

H-Block Test Results

- Interferers in the upper portion of the H-Block produced harmful interference (Receiver Overload) at -28 dBm for CDMA handsets and for UMTS handset operating at room temperature
  - The UMTS handset was very sensitive to high temperature, with overload occurring at -36 dBm at 100°F. The higher temperature caused its receive filter to drift, providing less rejection at H-Block.
- Interferers in the middle portion of the H-Block (1917-1918 MHz) were 3 dB less sensitive (i.e., -25 dBm rather than -28 dBm).
- Interferers in the lower portion of the H-Block (1915-1917 MHz) were the least sensitive (-17 dBm), which would allow higher power operation in that portion of the band.
- Stringent power limitations are required in the H-Block to avoid harmful interference to PCS mobile receivers
  - +5 dBm (upper) and +8 dBm (middle) to address IM interference
  - +13 dBm (upper) and +16 dBm (middle) to address Receiver Overload

Summary of H-Block Test Results

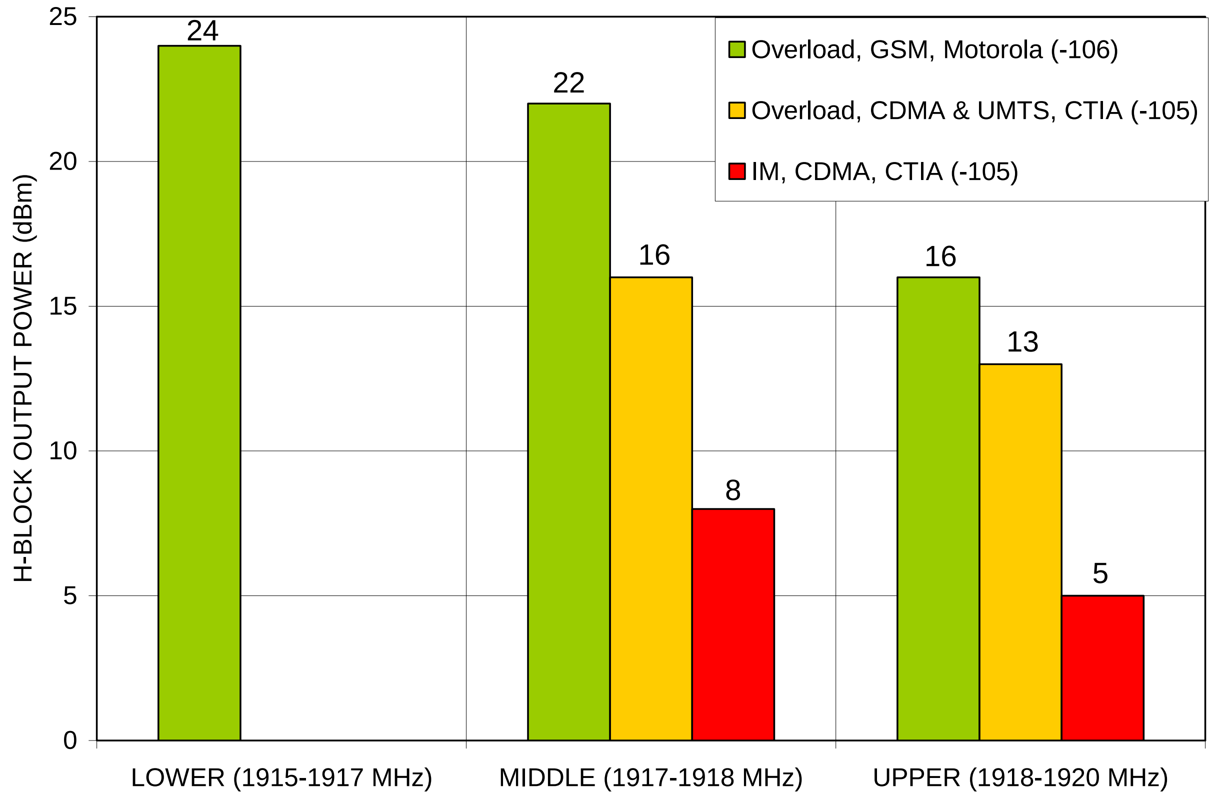
- Motorola & CTIA test results show Receiver Overload interference occurs at the levels indicated below in green and orange, respectively. Note that operations in the AWS-3 band would not cause IM interference (in red) to the AWS-1 and AWS-2 bands.



Source: V-COMM Presentation to FCC on Sep. 20, 2005, Verizon Wireless Ex Parte, WT Docket No. 04-356, Sep. 21, 2005

Required H-Block Mobile Power Limits

- Using Receiver Overload test results and “1 meter separation” with 3 dB additional loss, the H-Block mobile power limits shown below are required to prevent interference to PCS devices. Results for Motorola & CTIA are shown below in green and orange, respectively. IM interference (in red) is not an issue for AWS-3 band.
- The results show H-Block mobile transmissions can interfere with PCS mobile receivers due to receiver overload, and 13 MHz guard band is required for a +24 dBm mobile in lower H-Block spectrum (1915-1917 MHz), with lower power levels permitted in the middle and upper segments.



Source: V-COMM Presentation to FCC on Sep. 20, 2005, Verizon Wireless Ex Parte, WT Docket No. 04-356, Sep. 21, 2005

Applicability of H-Block Test Results to the AWS-3 Band

- The H-Block (1915-1920 MHz) is separated from the PCS receive band (1930-1990 MHz) by a 10 MHz guard band.
- Assuming a 10 MHz guard band between the AWS-1 mobile receive band and any mobile transmissions in the AWS-3 band, the H-Block test results can be analyzed to determine the interference to AWS-1 from AWS-3 mobile operations.
- Mobile transmissions in the AWS-3 band will cause harmful interference to AWS-1 mobile receivers in the form of Receiver Overload and OOBE.
- Mobile transmissions in the AWS-3 band will <u>not</u> cause IM interference to AWS-1 mobile receivers because IM products would not be produced “in-band” to those receivers.

Applicability of H-Block Test Results to the AWS-3 Band

Receiver Overload

- We assume uplink transmissions in the 2165-2170 MHz spectrum and ignore the impact to AWS-2 mobile receivers. (See Motorola's AWS test results for more discussion about impact on AWS-2)
- Applying the H-Block results, we conclude that receiver overload would occur in AWS-1 receivers at -28, -25, and -17 dBm for uplink transmissions in the 2165-2167, 2167-2168, and 2168-2170 MHz bands, respectively.
- To protect the AWS-1 band, AWS-3 mobile power should be limited to +14, +17 and +25 dBm for uplink transmissions in the 2165-2167, 2167-2168, and 2168-2170 MHz bands, respectively.
  - Based on path loss of 39 dB (1 meter @ 2165 MHz) and additional loss of 3 dB, for total of 42 dB (Note: This is 1 dB less than path loss for PCS @ 1900 MHz)
  - Assumes AWS-1 devices use front-end receive filters that are optimized for only AWS-1 band. Actual filters manufactured for multiple bands can be expected to experience less rejection and worse interference.
- Avago filter analysis concludes that a minimum guard band of 13 MHz would be needed to adequately attenuate AWS-3 adjacent band interference.

Applicability of H-Block Test Results to the AWS-3 Band

OOBE

- H-Block tests confirm that AWS-3 mobile transmissions will cause harmful OOBE interference to AWS-1 mobile receivers.
- OOBE cannot be filtered at the victim receiver because it's received as in-band noise, and must be mitigated at the transmitter.
- CTIA's H-Block tests for AWGN in-band noise conclude that harmful interference occurs at -117 dBm.
- An AWS-3 OOBE limit of -75 dBm/MHz RMS in the 2110-2155 MHz band is needed to protect AWS-1 mobile receivers.
  - Based on path loss of 39 dB (1 meter @ 2165 MHz) and additional loss of 3 dB, for total of 42 dB
  - This is comparable to the OOBE limit of -76 dBm/MHz derived from CTIA's H-Block tests, and is consistent with industry standards.
- Avago filter analysis concludes that a minimum guard band of 12.5 MHz would be needed to adequately attenuate AWS-3 OOBE.

Review of Motorola's AWS Test Procedures

- Motorola recently conducted AWS-3 receiver overload tests using a prototype AWS-1 band CDMA handset as the victim receiver. (Motorola's AWS test data is filed in the instant proceeding.)
- Motorola's tests used the same test plans and procedures as used by CTIA for H-block testing
- Case1 & Case2 tests were conducted at -100 and -105 dBm levels to represent low signals occurring indoors and during fades
- The interfering sources included CDMA and CW signals at the center frequencies 2156.25, 2157.5 and 2162.5 MHz.
- The victim receiver was operated in the upper portion of the AWS-1 band with center frequency at 2153.75 MHz (i.e., using standard CDMA channel assignment with 625 KHz internal guard band).
- Motorola also measured the rejection of the AWS-1 device's receive filter in the 2155-2175 MHz spectrum, and observes the filter provides negligible attenuation in this spectrum (i.e. 0-2 dB).

Results of Motorola's AWS Tests

- For the faded condition (Case2), an interference level of -34 dBm caused a dropped call to the victim AWS-1 handset.
  - This result was observed for all three AWS-3 interferers; i.e., operating at 2156.25 MHz, 2157.5 MHz, and 2162.5 MHz.
  - We focus on the results for CDMA interferers because they are more representative of signals in AWS-3 bands than CW signals, and show worse interference.
- Motorola's use of a "dropped call" as the interference reference point for its AWS test is representative of an extreme measure of interference.
- Previous H-Block testing used degradation in call quality, as measured by an increase in Frame Error Rates, as the appropriate reference point.
- Based on analysis of lab test data, impairments to call quality occur about 8 dB (typical value) before a call drops, indicating an occurrence of harmful interference at lower levels (i.e., -42 dBm).

Analysis of Motorola's AWS Tests

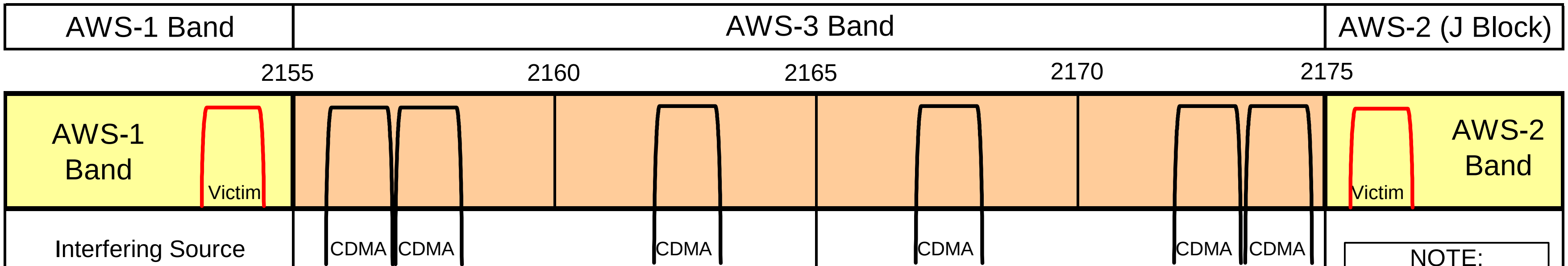
- We can conclude from Motorola's tests that AWS-1 devices will begin to see harmful interference from AWS-3 transmissions in the adjacent band when faced with an interfering signal of -42 dBm.
- With receiver overload interference occurring to AWS-1 devices with AWS-3 interference as low as -42 dBm, the power of AWS-3 mobiles transmitting in the 2155-2165 MHz band must be limited to 0 dBm (1 mW) to avoid harmful interference to AWS-1 devices.
  - Based on path loss of 39 dB (1 meter @ 2155 MHz) and additional loss of 3 dB, for total of 42 dB
- While Motorola did not test the impact on AWS-2 devices operating in the 2175-2180 MHz band, we can conclude that such devices would be subject to similar receiver overload conditions, and that AWS-3 mobile devices transmitting in the upper half of the AWS-3 band (2165-2175 MHz) must be similarly limited to 0 dBm (1 mW) to provide adequate protection for the AWS-2 band.

Adjacent Channel Interference Results
(Considers Protection of AWS-1 Only)

AWS-1 Band	AWS-3 Band				AWS-2 (J Block)
	2155	2160	2165	2170	2175
AWS-1 Band (Victim)					AWS-2 (J Block)
Interfering Source	CDMA CDMA	CDMA	CDMA CDMA CDMA		NOTE: This analysis does not consider interference protection for AWS-2 (J-Block).
Receiver Overload Interference Occurs at AWS-1 Device (dBm)	-42 dBm		-28 -25 -17 (dBm)*		
Maximum Mobile Power to Prevent Interference (dBm)	0 dBm EIRP		+14 +17 +25 (dBm EIRP)*		
Test Data filed in FCC Proceeding	AWS-3		PCS H-Block		
Submitting Party	Motorola		CTIA CTIA Motorola		
Victim Device Technology and Test Signal Level	CDMA Device (-105 dBm)		CDMA CDMA GSM (-105) (-105) (-106)		

- Interference protection for AWS-1 is considered above, but no protection for AWS-2 band. For protection to AWS-1 & AWS-2 bands, the results shown for 2155-2160 should apply to the entire AWS-3 band.
- Tests were not conducted with interfering signals in the 2165-2170 MHz band segment. The results provided in this column (above) are from the H-Block tests, which represent a 10 MHz guard band separation between this band segment and the AWS-1 band. These test results assume an optimized filter for AWS-1 devices, which does not exist today. Actual AWS-1 device filters exhibit less rejection to AWS-3 spectrum in the 2165-2170 MHz spectrum (i.e. 10 to 20 dB less than PCS filters for H Block), and will experience interference at lower levels than shown above for 2165-2170 MHz.

Adjacent Channel Interference Results
(Considers Protection of AWS-1 and AWS-2)



	AWS-3 Band		AWS-2 (J Block)
Receiver Overload Interference Occurs at AWS-1 Device (dBm)	-42 dBm	-42 dBm	NOTE: This analysis considers interference protection for both AWS-1 and AWS-2 (J-Block).
Maximum Mobile Power to Prevent Interference (dBm)	0 dBm EIRP	0 dBm EIRP	
Test Data filed in FCC Proceeding	AWS-3	AWS-3	
Submitting Party	Motorola	Motorola	
Victim Device Technology and Test Signal Level	CDMA Device (-105 dBm)	CDMA Device (-105 dBm)	

- Interference protection for AWS-1 Bands & AWS-2 (J-block) are considered above.
- The impact to AWS-1 band is based on Motorola’s AWS band test results with interferers in 2155-2165 MHz band segment.
- Tests were not conducted with interfering signals in the 2165-2175 MHz band segment. The results provided in this column (above) are based on the analysis of Motorola’s AWS tests with interferers in the 2155-2165 band segment, which represents no guard band separation to AWS-1 band. Similar results are assumed to the AWS-2 band for interferers in the 2165-2175 MHz, which is adjacent with no guard band separation.

Other Potential Interference Issues with AWS-3 Uplink Transmissions

- Base-to-Base interference is also possible with AWS-3 uplink transmissions
  - If AWS-3 base station receive spectrum is immediately adjacent to AWS-1 or AWS-2 base transmit spectrum, interference can occur when CMRS base stations co-locate (or locate adjacent to another), which is common practice and a requirement in many local zoning districts.
  - Some guard band separation or physical distance separation is required for this operation to prevent interference.
- AWS-3 to AWS-3 mobile-to-mobile and base-to-base interference is also possible if the band segments are separately licensed and deployed
  - In some of these cases, there would be no guard band separation between uplink and downlink bands, which increases the potential for mobile-to-mobile and base-to-base interference.

Summary of AWS-3 Band Interference

Receiver Overload Interference

- To prevent receiver overload interference to AWS-1 and AWS-2 devices, the power of AWS-3 mobile devices must be limited to 0 dBm EIRP (1 mW) – from analysis of Motorola's AWS tests.
- Avago states that 13 MHz of guard band separation is required to achieve sufficient receive filter rejection from full-power AWS-3 devices, to prevent receiver overload interference to AWS-1 devices.

OOBE Interference

- To prevent OOBE interference to AWS-1 and AWS-2 devices, the OOBE of AWS-3 devices must not exceed -75 dBm/MHz – from CTIA's tests.
- Avago states that 12.5 MHz of guard band separation is required to achieve sufficient transmit filter rejection, to prevent OOBE interference to AWS-1 and AWS-2 devices.

Conclusions

- AWS-3 uplink transmissions will cause harmful interference to mobile devices in the adjacent AWS-1 and AWS-2 bands due to OOBE and receiver overload mobile-to-mobile interference.
  - Significantly limiting the uplink power levels of AWS-3 devices is possible (i.e. power limit of 0 dBm), but not practical for CMRS type service that requires higher power levels to sustain reverse links to the base stations.
  - To prevent interference to adjacent bands, AWS-3 should be designated for downlink transmissions only or should be used for fixed services.