Roberson and Associates, LLC
Technology and Management Consultants

Technical Analysis of the 35x35 MHz Band Plan

Prepared for T-Mobile, USA
by Roberson and Associates, LLC
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Overview

- T-Mobile is grateful to the FCC for its interest in maximizing licensed spectrum in the 600 MHz auction
- T-Mobile favors a band plan that maximizes paired spectrum, promotes interoperability, and enhances competition.
- The 35x35 MHz band plan that T-Mobile proposed creates more high-value spectrum for competitive bidding and wireless competition with fewer design trade-offs and interference hazards than other alternatives.

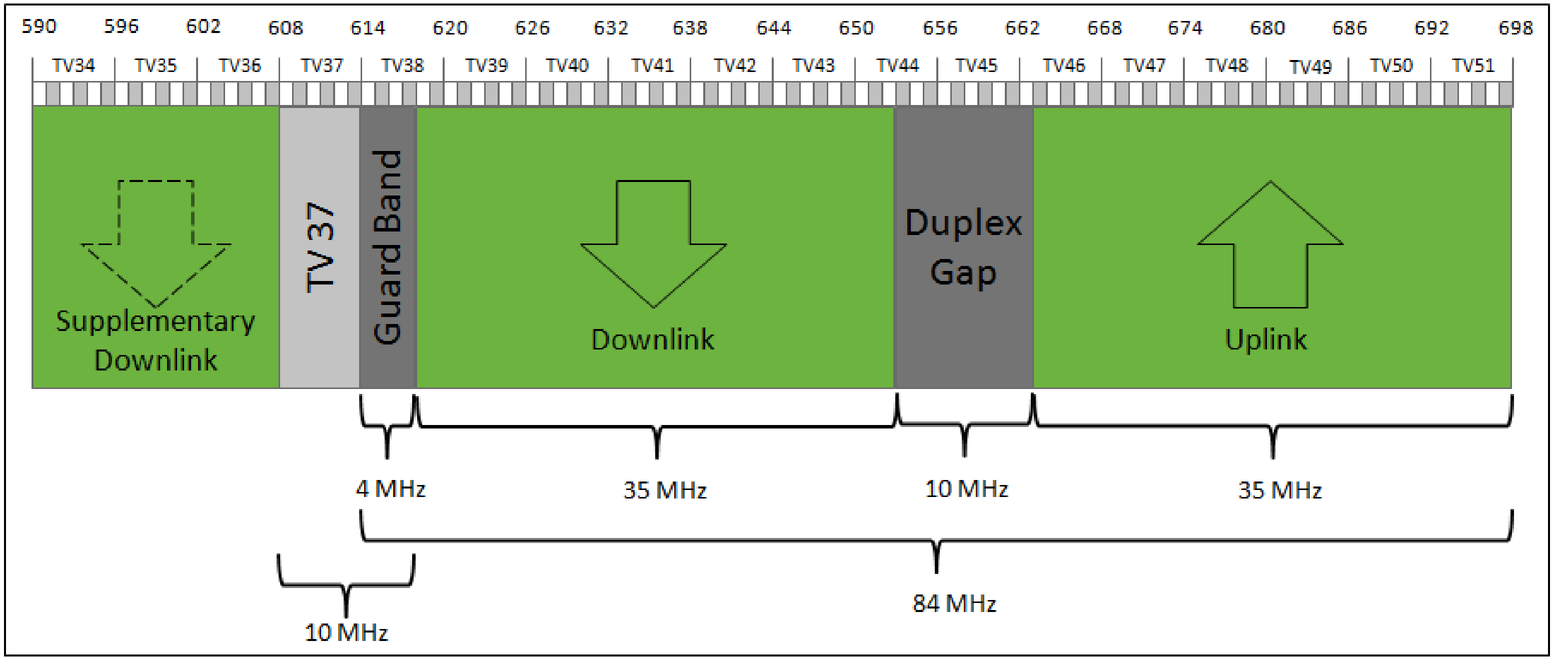
Technical Analysis Summary: A 35x35 MHz Plan Is Readily Feasible

- Performance, design, and interference issues are few and costs are reasonable
- Well-established mitigation techniques and current-generation technologies resolve or substantially mitigate the few issues that exist
- Near-term technical advances reduce costs and increase performance further

Roberson & Associates' Band Assessment Methodology

- Define analysis criteria
- Identify technical issues
- Assess the feasibility and cost of solutions or mitigations
- Compare the costs and benefits of 35x35 MHz plan to those of alternative band plans in a two-phase assessment:
  1. 35 x 35 MHz Band plan-specific issues
     - User Equipment (UE) device antenna size and performance
     - Radio frequency duplex filter performance
     - UE device harmonic interference to other CMRS bands
  2. Common issues
     - Optimizing the 600 MHz duplex gap for maximum licensed spectrum with minimum risk of interference
     - Potential interference to and from broadcast television operations

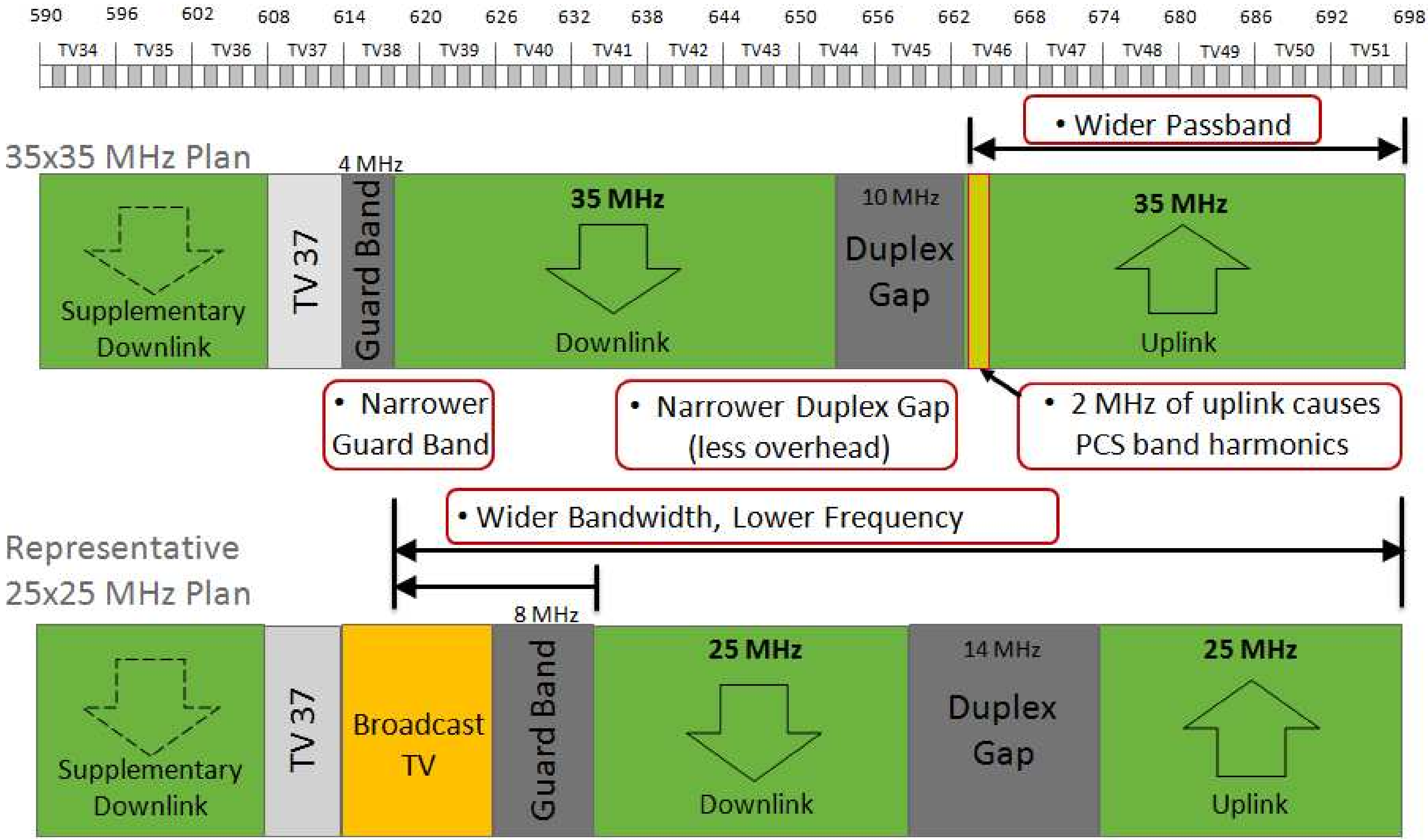
35x35 MHz Band Plan



- Advantage: **40% more spectrum than 25x25 MHz**

- Assessment Approach /Analysis Criteria
  - Identify and resolve or mitigate technical issues (2014-2015 technology)
  - Preserve capacity advantage
  - Cost competitive with current devices
  - Do no harm to existing users

Band Plan Comparison



Band Plan-Specific Issues are Readily Manageable

- Antenna Length and RF Performance
  - Wider bandwidth, lower frequency → longer antenna
  - Resolved by:
    - Re-tuning of 700 MHz antennas, slightly lower efficiency
    - Minimal 0.4 cm^3 size increase in a typical microstrip antenna versus 25x25 MHz band plan antenna falls within smartphone form factor
- Duplexer Filter Bandwidth
  - Larger pass band → greater filter design complexity
  - Resolved by:
    - Using dual filters consistent with current technology and industry practices
    - Migrating to single filter using 2015/2016 technology advances, if appropriate
- Harmonic Interference
  - Lower Uplink frequency→ 3rd Order Harmonic in PCS Band
  - Resolved by:
    - Low power level of third harmonic
    - Standard harmonic filter at the transmit side
    - Augmented isolation between transmit and receiver paths

Device Antennas for 35x35 MHz Band Plan Are Priced and Sized for Rapid Commercial Deployment

Technical Issue	Performance Issue(s) or Concern(s)	Resolution Approach(es)	Result
• Single device antenna covering wider bandwidth	• Antenna Length Increase causes slight -0.32 dB detuning (vs 25x25 plan) • Antenna efficiency causing degraded detuning of -0.6 dB (vs 700 MHz antenna)	• Larger antenna size compatible with handset • Optimize antenna for 600 MHz uplink • Increase base power • Advanced antenna design*	• Capacity still exceeds other plans significantly • Negligible throughput decrease • Minor antenna structure size increase-compatible with (4-5 inch smartphones) • Advanced antenna designs resolves issues

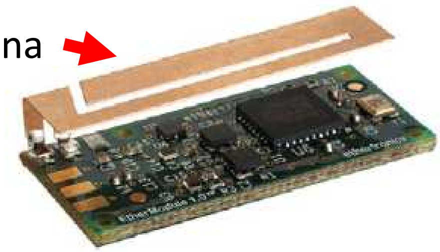
•Use of typical 3-5 cm^3 active antennas, innovative printed circuit board antennas, and other technological advances already in place in existing smartphones, or under development at half the size of a traditional passive antenna

LTE Antennas Can Support a 35x35 MHz Band Plan in Commercially Acceptable Form Factors

Antenna

Pulse Electronics (3.2 cc)

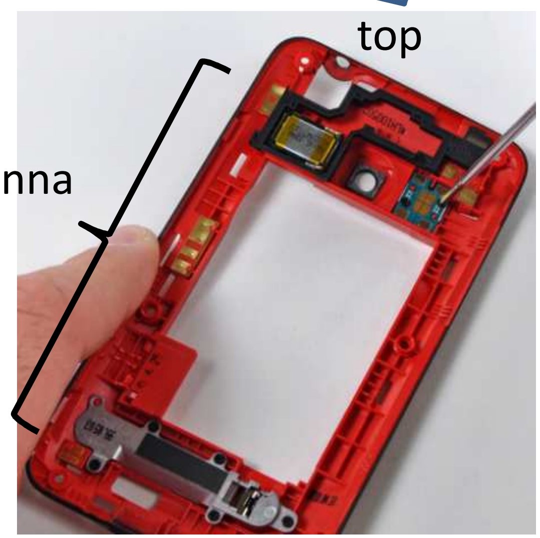
Antenna



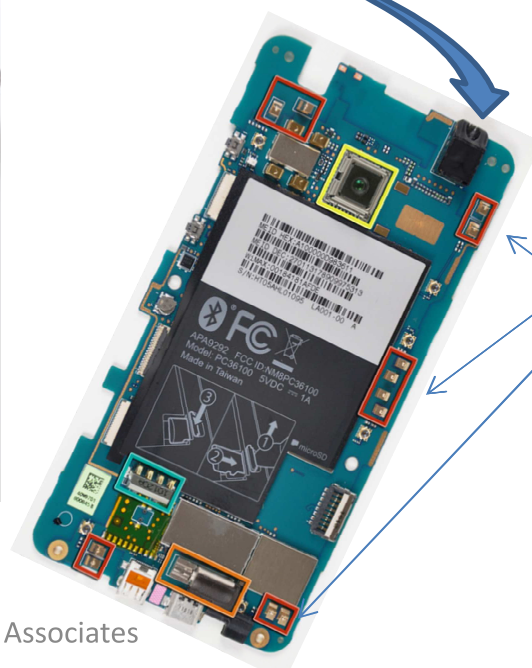
Etheretronics (33x15x11 mm^3)

top

Antenna



HTC Evo LTE smartphone



Antenna Connectors

Duplex Filter Solutions Exist for 35x35 MHz Band Plan

Well known, current industry practice uses dual-filter configuration for wide pass band

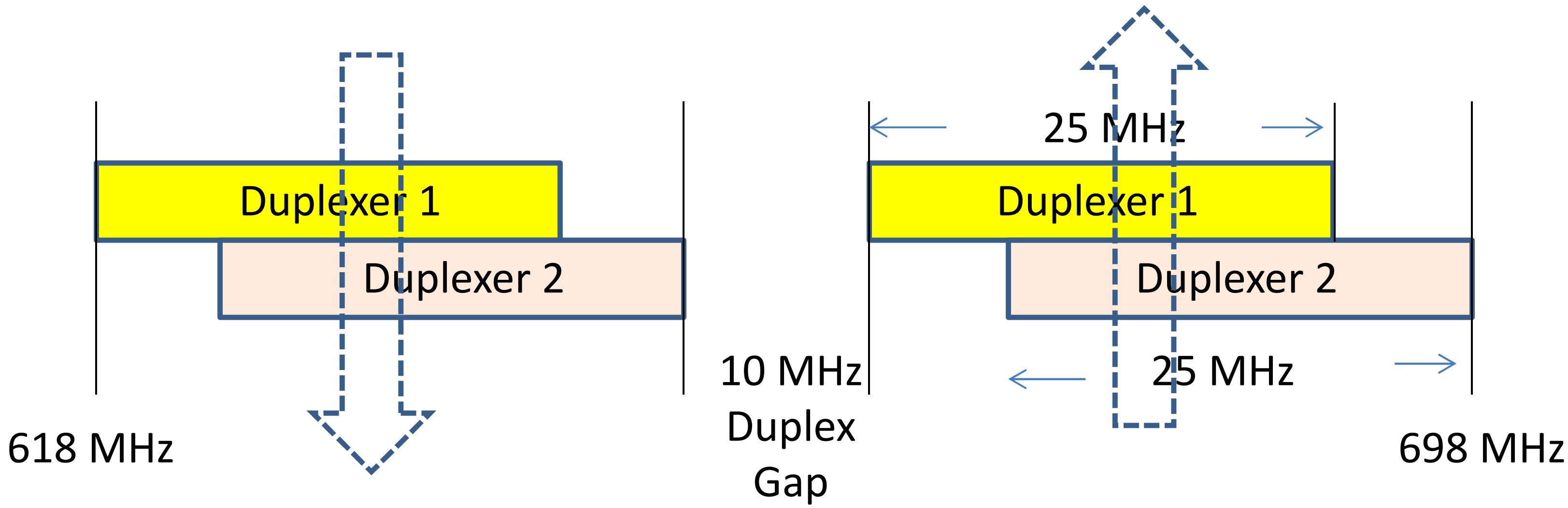
Technical Question	Performance Issue(s) or Concern(s)	Resolution Approach(es)	Result
• Filter Design for Wide Pass band	• Appropriate filter response characteristics for 35 MHz pass band	• Dual, overlapping duplex filter structure* • Advanced duplexer materials	• Required performance achieved • Slight cost increase, mitigated by unit volumes • Advanced duplexer approaches resolve issues*

*Migration to a single filter solution feasible in the 2015 timeframe as technology advances

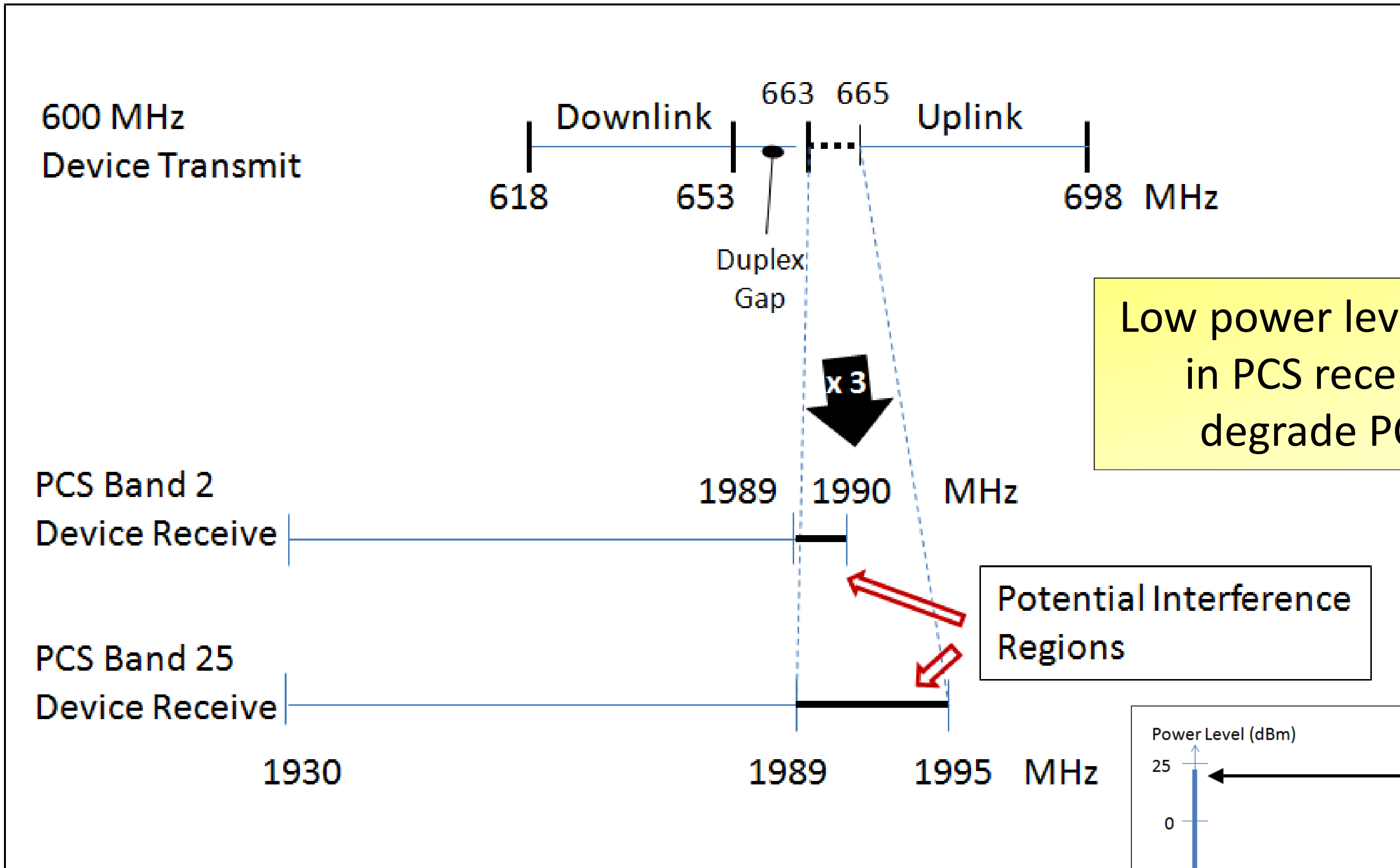
Dual Duplex Filters Can Cover an Expanded Pass Band

- Current (single) duplex filters support 28-30 MHz pass band
- 25 MHz overlapped filters achieve 35 MHz pass band

2.5 x 2.0 x 0.7 mm

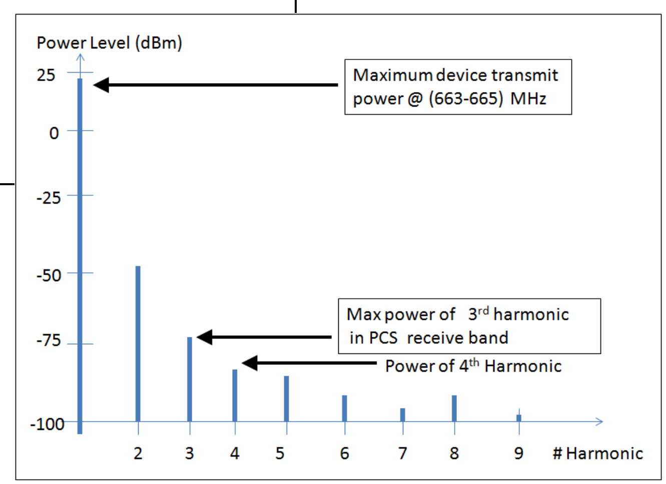


Harmonic Effects Raise Few Concerns



Low power level of third harmonic in PCS receive band will not degrade PCS performance

User device transmitter creates harmonic effects at multiples of the uplink frequency, but each multiple has progressively lower power



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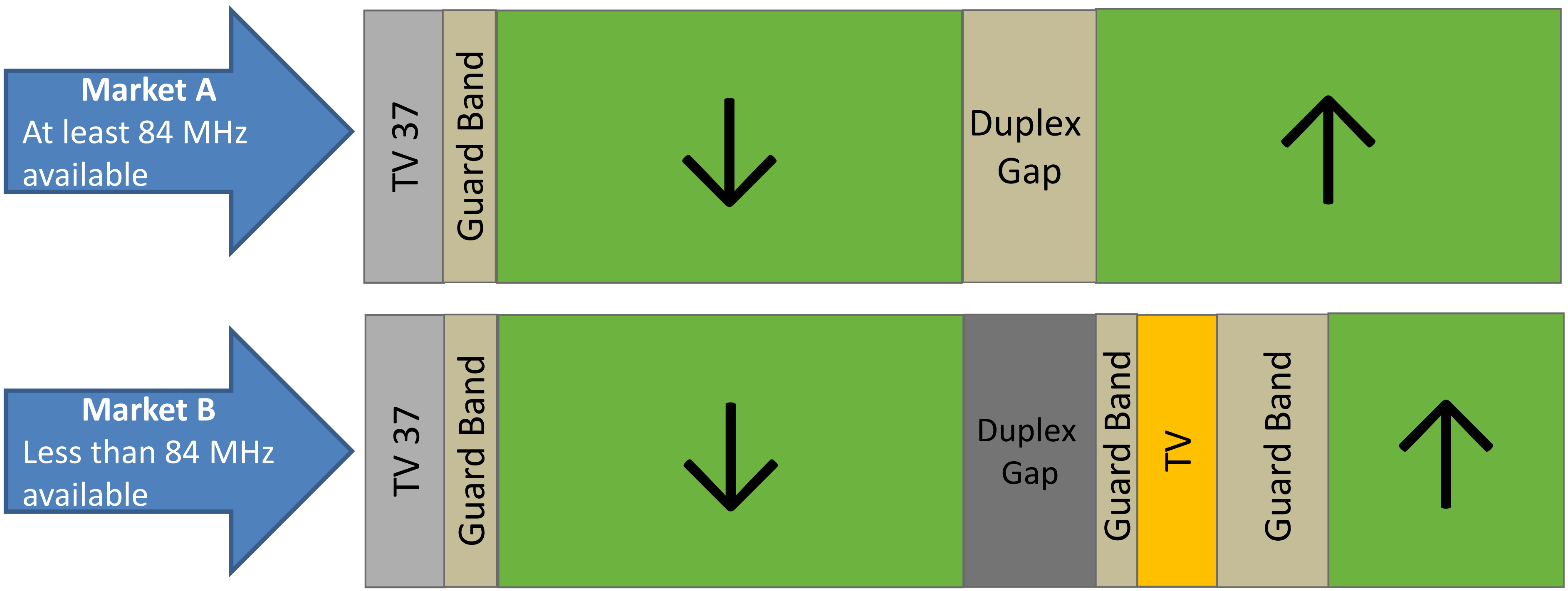
Mobile –TV Co-existence Introduction

- First, set the Duplex Gap location for mobile broadband
- Second, allow the broadcast stations “eat” into the uplink in certain markets when necessary
- Both assumptions incorporated in the FCC and T-Mobile proposed band plans
  - Reduces the number, scope, and scale of interference scenarios
  - Prevents a few markets from reducing the broadband spectrum available elsewhere



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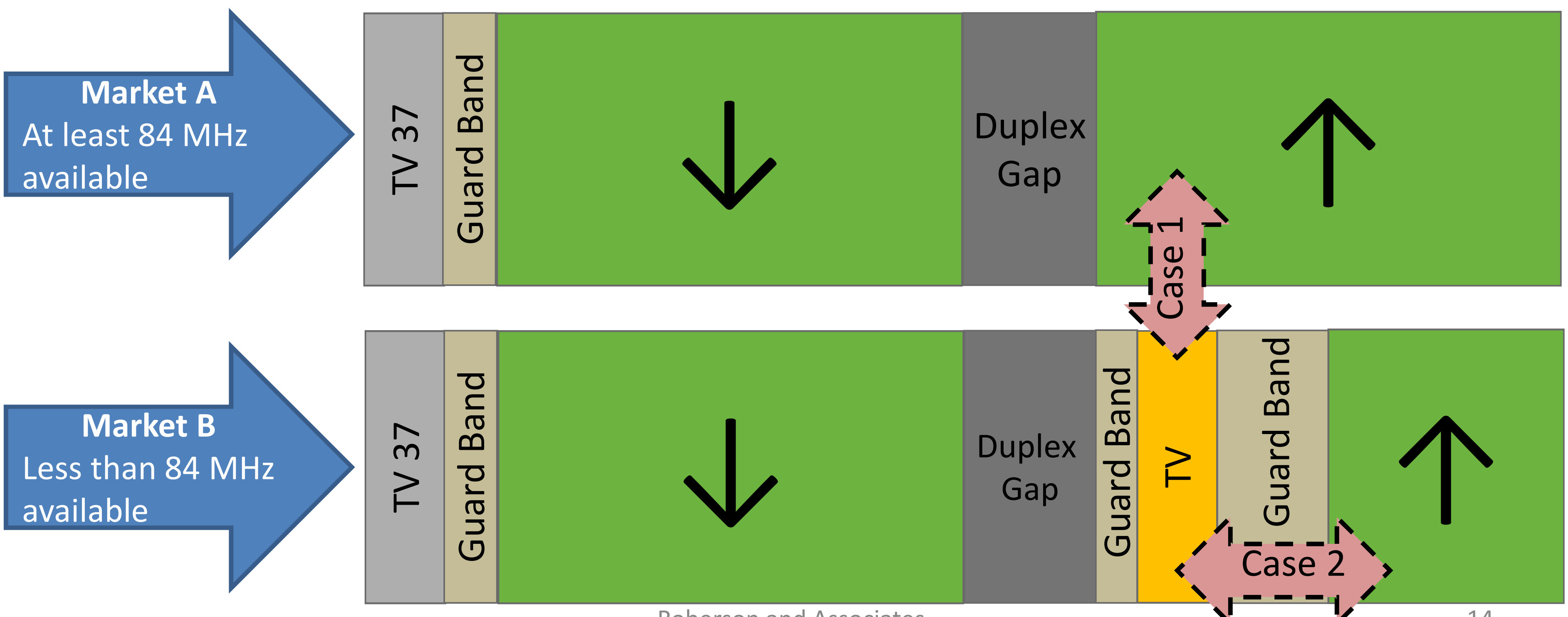
Mobile –TV Co-existence Cases

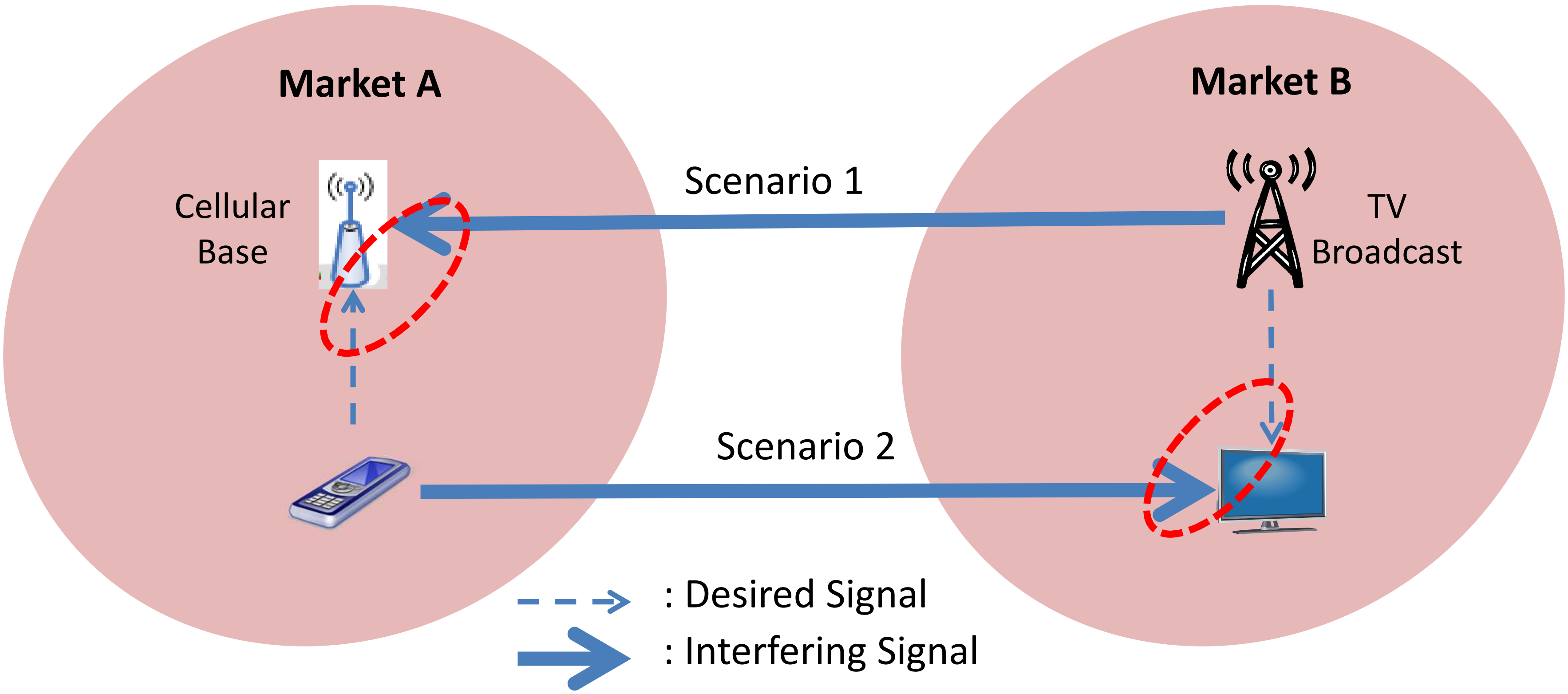
Analysis will focus on broadcast TV in the Uplink

Case 1 – Adjoining Geographic Region, Co-Channel
- **Scenario 1**: Address TV interference with cellular uplink (at base receiver)
- **Scenario 2:** Address Cellular UE device interference with TV receiver

Case 2 – Overlapped and Adjoining Geographic Regions, Non Co-Channel
- Address TV interference with cellular uplink (at base receiver)



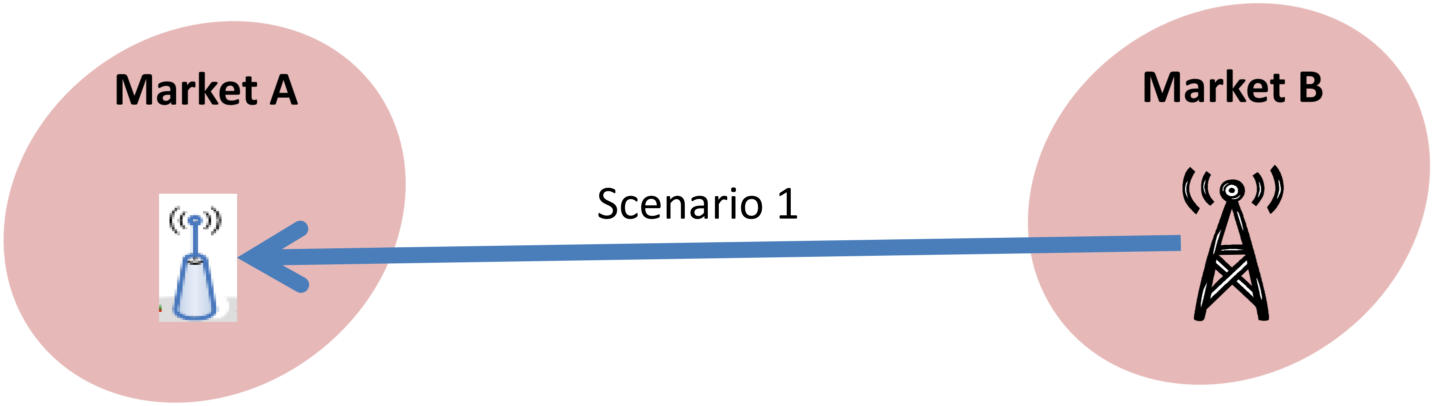
Case 1 – Adjoining Geographic Region, Co-Channel



Scenario 1 – High power TV broadcast to base station receivers. Kilowatt TV transmitters transmitting into cellular base station receivers designed to receive microwatt power levels.

Scenario 2 – Low power mobile handsets to TV receivers. milliwatt device transmitters transmitting into TV receivers designed to receive microwatt power levels.

Case 1, Scenario 1 – TV to Cellular Base Station Receiver



Concern: Kilowatt TV transmitters transmitting into base station receivers, often above clutter, designed to receive microwatt power levels. Various estimates of potential impact from <u>110 - 360 km.</u>

Potential Technical Solutions:

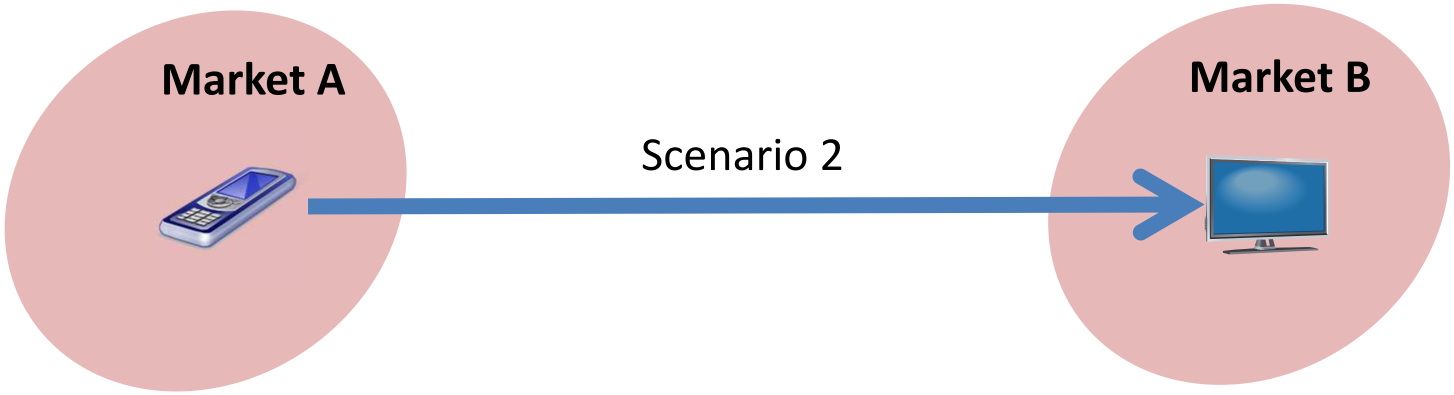
1. Ensure sufficient separation distance to allow TV signal to attenuate through propagation loss.
2. Advanced mitigation techniques such as orthogonal polarization, interference cancellation

Preliminary Conclusions:

1. We believe these techniques could reduce separate distance between a TV broadcasting transmitter to a base station receiver from 110-360 km to approximately **50 km**[1]
2. Given the physical size of MEA and EA market areas, that TV transmitters are often near the center of a market area, and there are fewer base stations at market boundaries, this interference scenario appears workable for carriers.

1. *See* CEPT Report 22B, available at http://www.erodocdb.dk/docs/doc98/official/pdf/CEPTRep022.pdf

Case 1, Scenario 2 –Mobile Handset to TV Receiver



Concern: Low power mobile handsets to TV receivers. milliwatt device transmitters transmitting into TV receivers designed to receive microwatt power levels.

Potential Technical Solutions:

1. Low power transmission nature of handsets means handset must be within meters of TV receiver to cause interference, not kilometers.
2. Since there is separation distance between the TV station and the cellular base station from Case 1, Scenario 1 and the coverage of the cellular system is small, the likelihood of the UE device interfering with a typical TV receiver is also small

Preliminary Conclusions:

1. Given the physical size of MEA and EA market areas, TV transmitters are often near the center of a market area. Since there are fewer base stations at market boundaries, this interference scenario has low likelihood.

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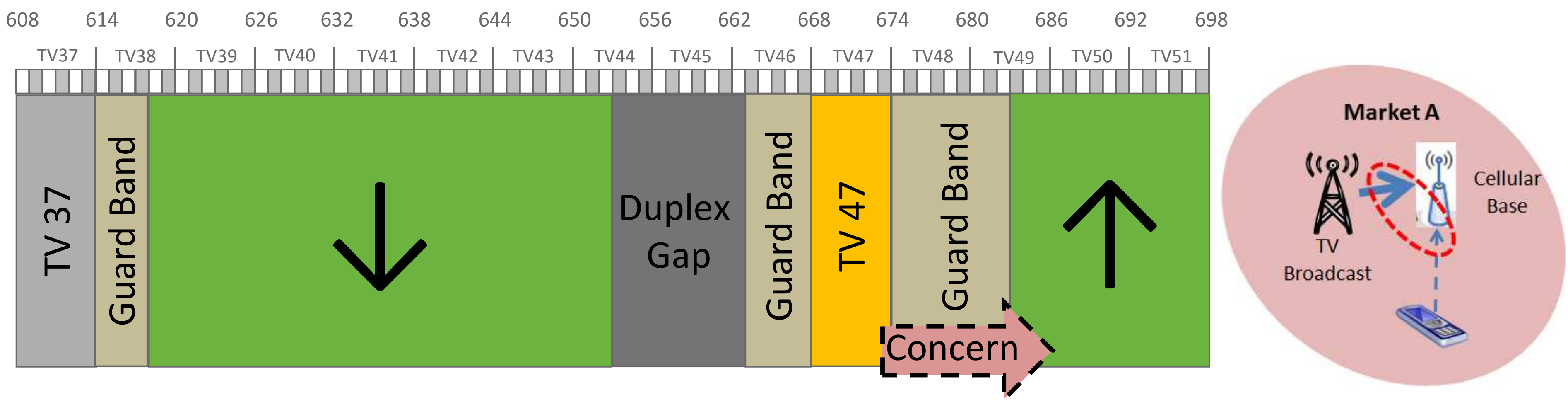
Case 2 – Overlapped and Adjoining Geographic Regions, Non Co-Channel



Concern: Kilowatt TV transmitters transmitting into base station receivers and mobile handsets transmitting into TV receivers. Primary interference concern is for base station receivers.

Potential Technical Solutions:

1. **9 MHz Nominal Guard band** between TV 47 (and TV 48 if necessary) and cellular uplink block
2. Place a moderate power TV transmitter (50 KW) into TV 47 instead of 1 MW

Preliminary Conclusions:

1. Large separation distance between TV and Base station not required (guard band can be used)
2. Prevents a few markets from reducing overall spectrum elsewhere
3. Occurs only when 13 TV stations (78 MHz) or less are recovered, not the usual situation.
4. This “eating” into the uplink provides some paired spectrum even if only 12 TV stations are recovered

Summary

- The 35x35 MHz band plan provides
  - Efficient usage of the spectrum
  - Maximum Feasible Operating Spectrum Above Channel 37
- The 35x35 MHz Plan is feasible
  - All technical issues are addressable
  - Leverages current industry practices and expected technology advances
  - Practical mitigation measures for potential interference both with other LTE systems and TV operations

Appendix

Filtering and Frequency Selection Solve Modest Harmonic Effects

The low power and relatively low likelihood of occurrence of harmonic power into the PCS band can readily be addressed by better isolation and harmonic filter technology.

Technical Question	Performance Issue(s) or Concern(s)	Resolution Approach(es)	Result
• Harmonic power of user device transmitter	• 4.5% Interference with PCS band receiver (3rd harmonic) • Minimal Interference with BRS band (4th harmonic)	• Improved RF harmonic filter • Coordination of 600 MHz and PCS operation through frequency selection	• No degradation to PCS or BRS band device or user

Characteristics in Common with Other Commenter Proposed Band Plans

- Addresses intermodulation and large uplink/downlink separation issues of FCC Band Plan
- Channel 37 (608-614 MHz) to continue to be used for medical and other low power applications
- 5 MHz paired interchangeable FDD blocks
- Potential use of Supplementary Downlink (SDL) operations below the paired downlink boundary
- Leverages design approaches already being used in the 700 MHz band

Characteristics in Common with Other Band Plans

- Size of Duplex Gap
- Mitigation of TV Interference
- Relocation of the TV operations from the uplink spectrum because of substantial impact on cellular operations
- Coordination with the TV operations in Canada and Mexico to avoid co-channel and non co-channel interference

Duplex Gap and Allowable Applications

- A Ten Megahertz Duplex Gap Is Technically Feasible
- The Duplex Gap Can Support Useful Services
  - *Recommend* low power operations, such as wireless microphones or indoor unlicensed operations
  - *Do not recommend* high-power operations, such as television
    - Creates strong potential for intermodulation interference with 600 MHz downlink
    - Requires wasteful guard bands to provide sufficient attenuation to protect 600 MHz broadband services