LASER Inc.

Chicago 700 MHz A-Band

De Minimis Possibility of Interference with Channel 51

June 23, 2015

Who is Laser?

Overview and History

- Laser manages 12 MHz of Chicago 700MHz A-Band spectrum
- The uplink portion of the A-Band was formerly UHF broadcast Channel 52, adjacent to existing Channel 51
- This spectrum was previously owned by Cricket Communications, which was acquired by AT&T in March 2014
- Spectrum held in separate AT&T subsidiary, managed by Laser

Purpose

- Laser was formed to resolve any potential spectrum issues and determine an appropriate operator plan to bring this A-Band spectrum to market for use by Chicago consumers

Laser Waiver Request – Current Situation

Current FCC regulations restrict use of the entire A-block because of possible interference at the fringe of the WPWR-TV viewing area

Previous holder of license (Leap / Cricket) filed waiver in December 2013 to allow deployment, based upon thorough analyses and detailed showing of a lack of harmful interference to DTV viewers in the greater Chicago area

King Street Wireless currently holds an operative license on the A-Block in a portion of the WPWR-TV viewing area without any interference issues

The exponential rise in wireless data demand, the insignificant possibility of interference, and the uncertain path for additional spectrum argue for prompt action in the greater Chicago area, where high market values in recent AWS-3 auction highlight both scarcity and demand

The upcoming Broadcast Incentive Auction does not resolve this issue until 2020 at the earliest

Objectives for Today

- Share field test results which demonstrate that there is an insignificant likelihood of interference between the Chicago A-Block and WPWR-TV

- Any de minimis interference can easily be mitigated
  - Laser is willing to bear the potential cost

- Discuss next steps

Laser / OET Agenda

I. Laser test results and current operations prove de minimis interference

- These results complement and entirely support previous lab research findings (e.g., OET, Intertek, Ofcom, MSW)

II. The likelihood of interference with DTV signals from LTE is remote

III. In the unlikely event of interference to DTV signals, multiple mitigation paths exist

I.

Laser test results and current operations prove de minimis interference

- These results complement and entirely support previous lab research findings (e.g., OET, Intertek, Ofcom, MSW)

Laser Field Testing – Summary of Key Findings

1. The D/U ratios found during prior laboratory testing were **confirmed** in the field

2. With a stronger DTV signal, any potential for interference from an adjacent band is virtually impossible

3. Gradual impact on television signal instead of binary, all-or-none "cliff effect" observed in lab findings

Current A-Block Operations in WPWR-TV Viewing Area

LTE service was launched on the King Street Wireless 700 MHz A-Block license, inside the boundary of the WPWR-TV Channel 51 viewing area, after King Street obtained a consent letter from Fox

Laser requested a similar consent letter from WPWR-TV, but Fox refused, claiming such consent <u>would result in service loss for more than 99% of WPWR-TV's service population</u>

Laser is unaware of any cases of interference for users operating on King Street Wireless's license

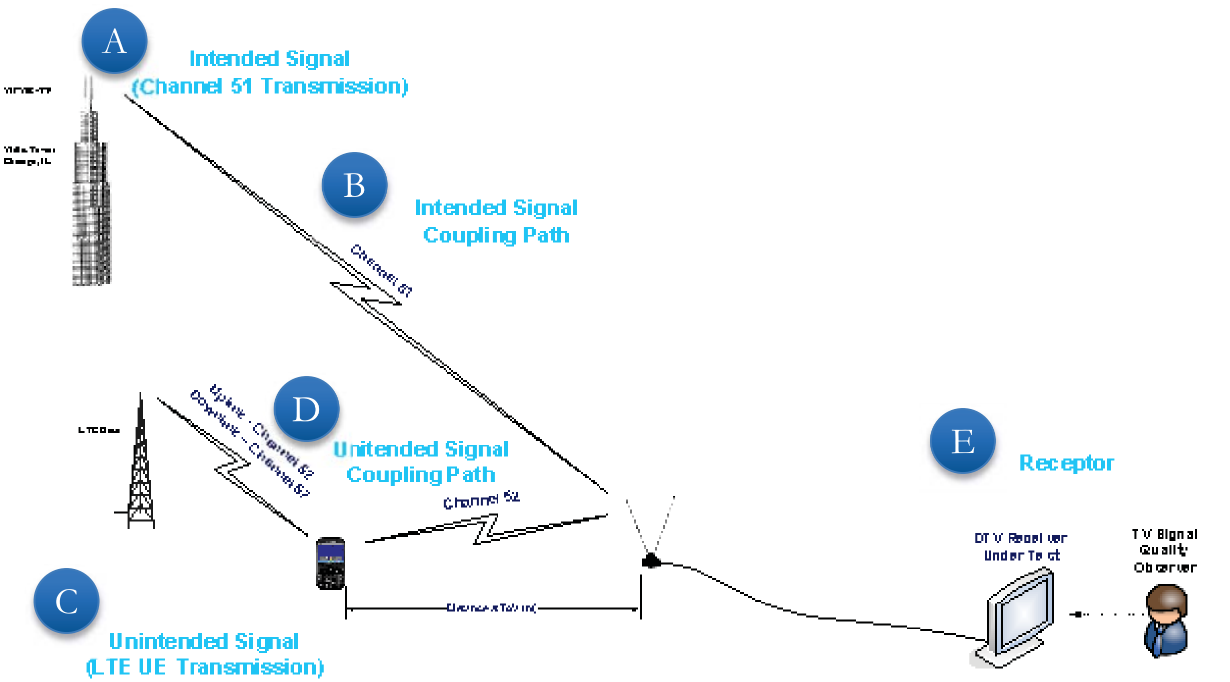
King Street Wireless 700 MHz A block sites are on the <u>fringe of the WPWR-TV viewing area</u>, where the DTV signal is weakest and the potential for interference is the greatest

This operating experience confirms the conclusions of both the technology measurements and the interference impact analysis that demonstrate **<u>interference from LTE UE to WPWR-TV DTV receivers will be de minimis</u>**

Interference Model At-a-Glance

- **Laser's analysis examines the theory, the physics and the components necessary to accurately and decisively measure potential interference between Channel 51 and the 700MHz A-Block in real-world settings**

Interference Schematic



Key Components

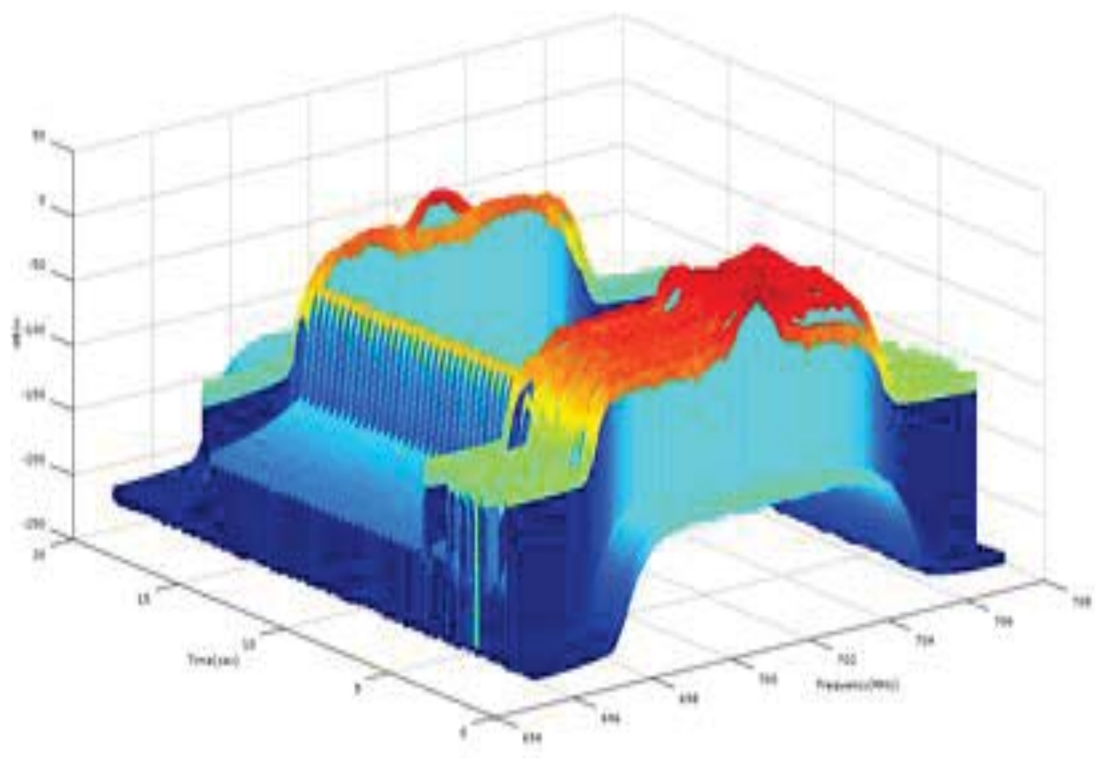
- A — Intended signal (Broadcast Ch. 51)
- B — Coupling Path of Intended signal
- C — Unintended signal (Transmission of LTE handset)
- D — Coupling Path of Unintended signal
- E — Receptor (DTV Receiver and end-user)

Objective:

The interference model seeks to measure the degradation in E at various transmission powers of C and various distances between C and E, all while each component operates at practical, real-life levels

Overview of Laser Testing Methodology

- Software Defined Instrumentation
- Real-Time Signal Analysis
- Spectrum Record and Playback
- More than just the physical layer analyzed



Comparison of Components - 1986 vs. Today

- **Since the 1986 Technical Advisory Committee work upon which Section 27.60 is based, wireless transmission power has decreased by 98%, while television interference protections have greatly advanced through six generations of chipsets**

Wireless

Category	1986	Improvement Factor	Today
Network	1st generation high-powered analog cellular	**3 generations**	4th generation digital LTE
Power	8.0W handsets	**98% reduction**	0.2W handsets
Cell Site	20-30 mile cell sites	**10x-80x+**	1-2 mile cells (even pico & femto cells)
Configuration	TDD	**No adjacent base**	FDD

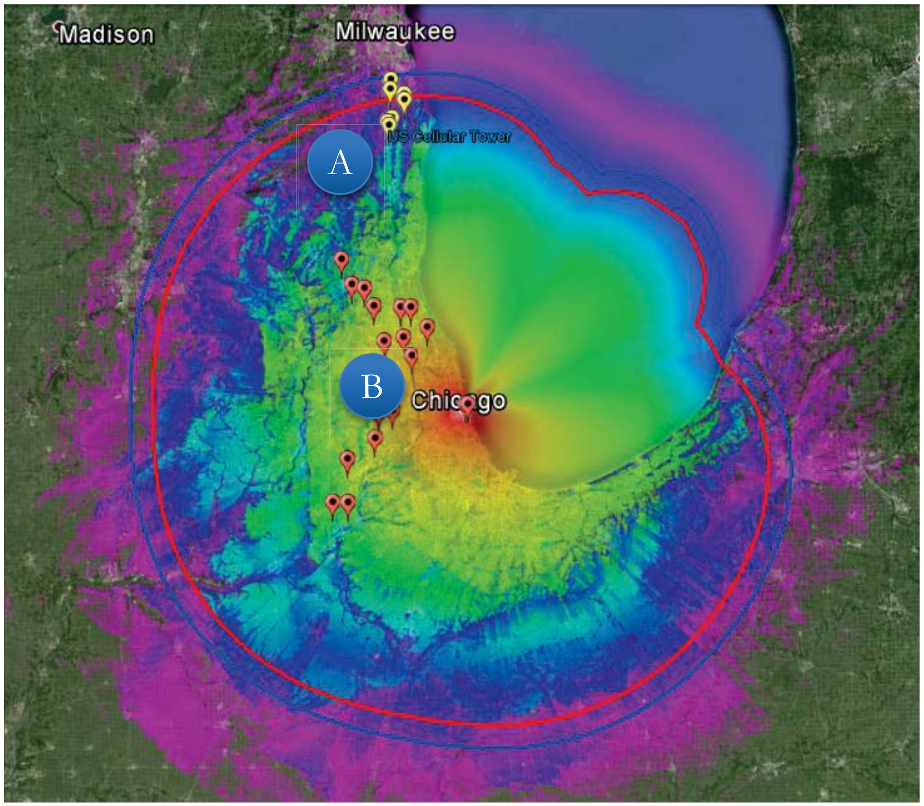
Television

Category	1986	Improvement Factor	Today
Tech	Analog (first-gen DTV chipsets not launched until 1998)	**6 generations**	Digital TV using 6th generation chipsets
Equalization	N/A (first gen DTV: 10dB)	**100x+**	35dB+
Ghost protection	N/A (first gen DTV: -3/+20µSec)	**60x+**	+/- 73µSec

Varied Placement of Interference Model

- **Laser focused its testing efforts in two critical areas within the WPWR-TV Service Contour**

WPWR-TV Service Protection Contour(a)



Locations

A **Inside service contour in Southern Wisconsin**

- Via network operating on 700MHz A-Band licensed to King Street Wireless via waiver granted by Fox / WPWR-TV
- **Testing in worst-case conditions –** fringe of WPWR-TV viewing area where the DTV signal strength is weakest

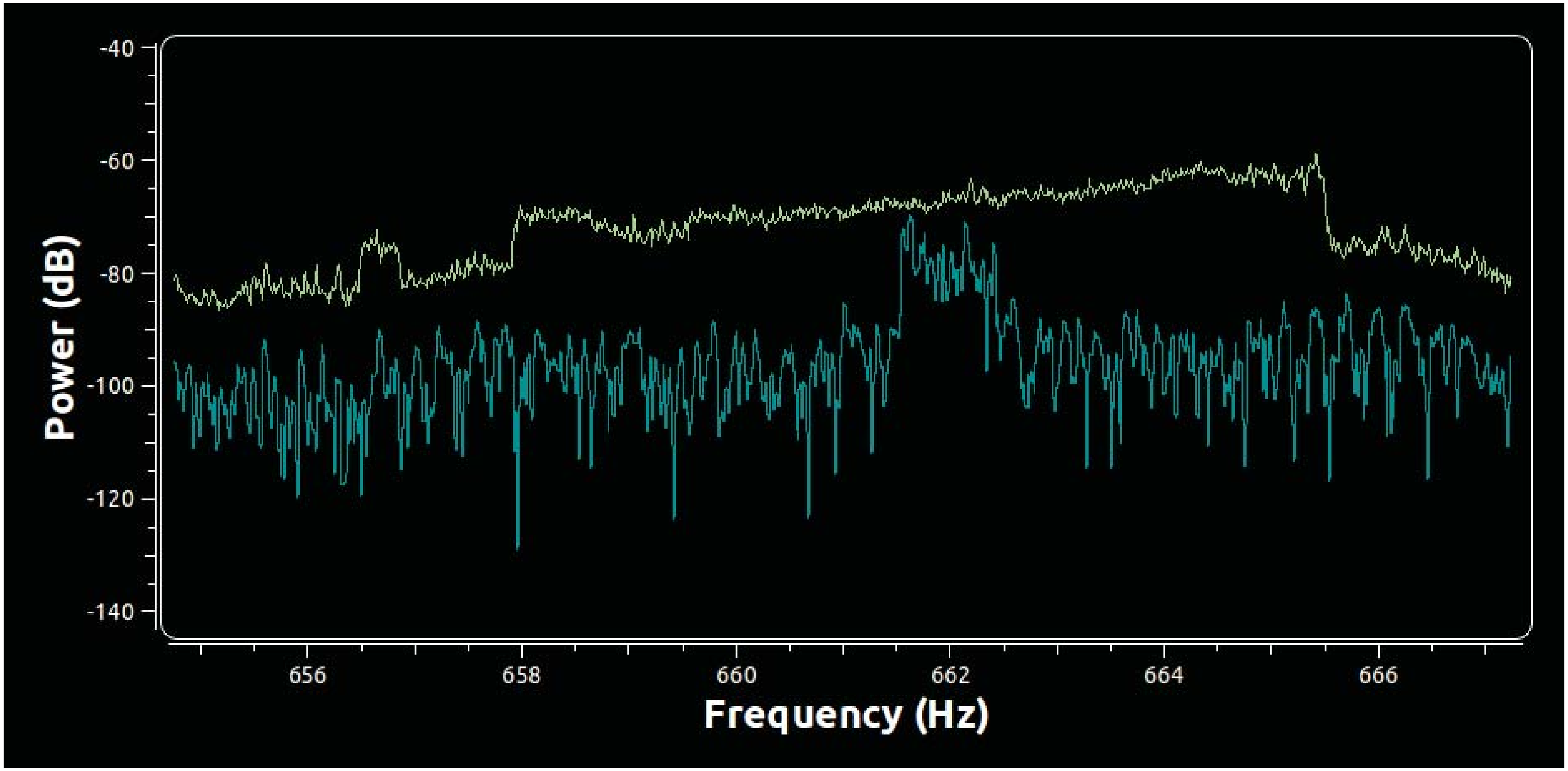
B **Central part of service area**

- Chicago and many major suburbs were tested
- Used in-phase and quadrature ("IQ") recordings of live LTE transmissions to simulate an LTE UE transmission

(a) 42.1 dBu service contour and service contour plus 8 km protection distance calculations were performed by Hammett and Edison, adjusted for the dipole factor, as required by paragraph 168 of the February 23, 1998 MO&O to the Sixth R&O of MM Docket 87-268.

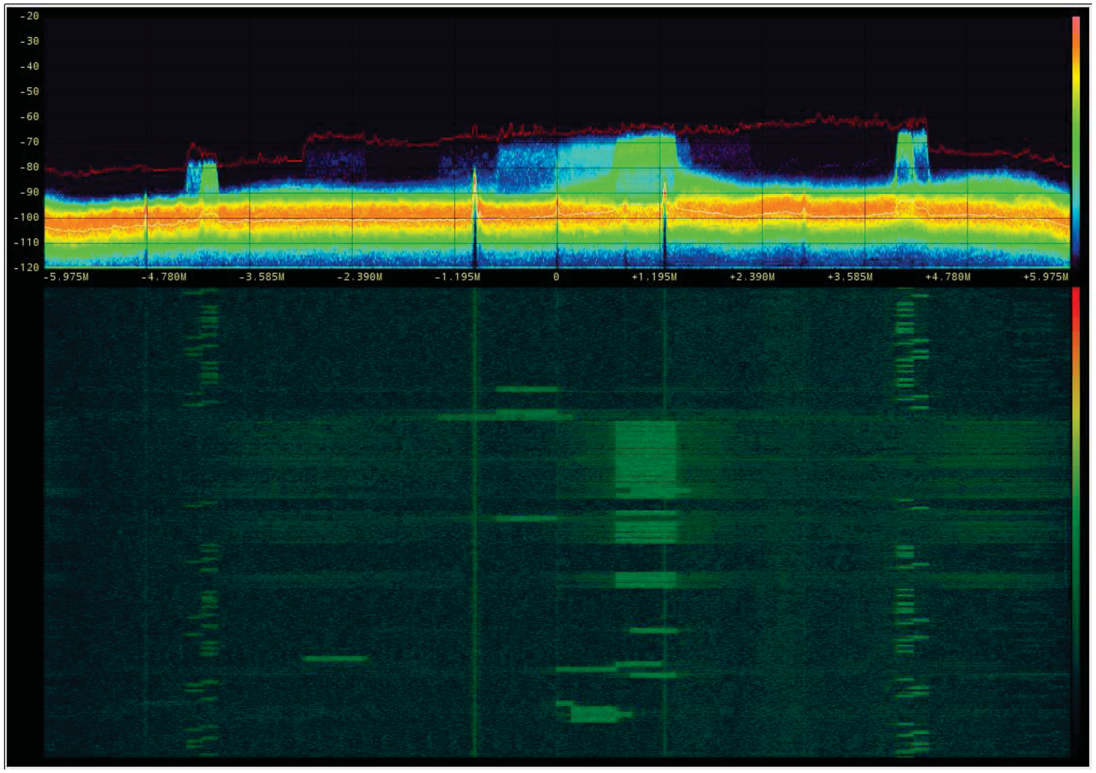
Traditional Spectrum Analyzers Provide an Inaccurate View of LTE UE Transmission Characteristics

- Using peak hold analysis (light green) is too pessimistic
- Using continuous sweep analysis (light blue) obscures transmission characteristics



Actual LTE Transmissions Are Far Less Likely to Cause Interference

- Real-time spectrum analyzers provide a more dynamic view of transmissions
  - — LTE transmits in short bursts
  - — ATSC forward error correction allows recovery of data lost to short bursts
- Histogram shows example of LTE UE transmission



Comparison of Precedent Test Results to Field Results

- **The D/U ratios found during prior OET, MSW and Intertek lab tests were confirmed by in-field testing**

Summary Observations

- As ATSC signal improves in amplitude and quality, strength of LTE UE transmission required for interference also increases
- The D/U ratios tend to decrease as DTV signal gets stronger and strong-signal effects become an increasing factor
- In stronger signal areas, it is unlikely and eventually impossible for LTE UE to transmit signal strong enough to cause interference, even when virtually touching DTV antenna

Prior Laboratory Test and Analysis Results

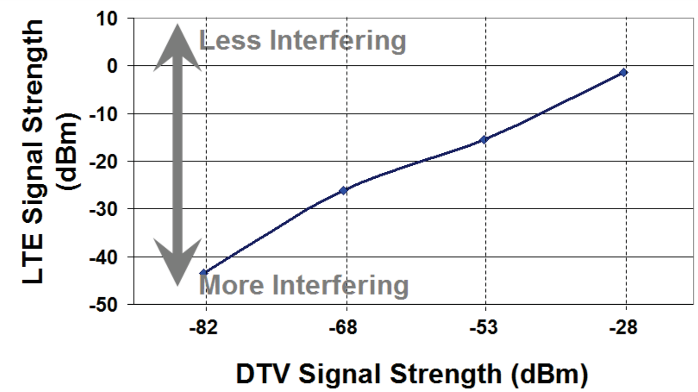
Reported Desired-to-Undesired (D/U) Signal Ratios [(1)]

	Analysis	Actual Laboratory Testing		
Study Done By	MSW for FOX	Intertek	MSW for CEA	FCC OET
D/U Ratio Before Interference Observed	-23 dB[(2)]	-35 to -40 dB	-46 dB	-38 to -45 dB
Study Publication Date	May 2013	January 2013	May 2014	6/17/14

1. A larger negative D/U number indicates greater immunity to an interfering signal. In this case, a larger negative number indicates a television is less likely to experience interference from an LTE device.
2. MSW/Fox used -23 dB to define interference; adjacent channel interference was not actually observed at this level

Field Results

LTE Signal Strength at the Threshold of Visibility



D/U Ratio as a Function of DTV Signal Level

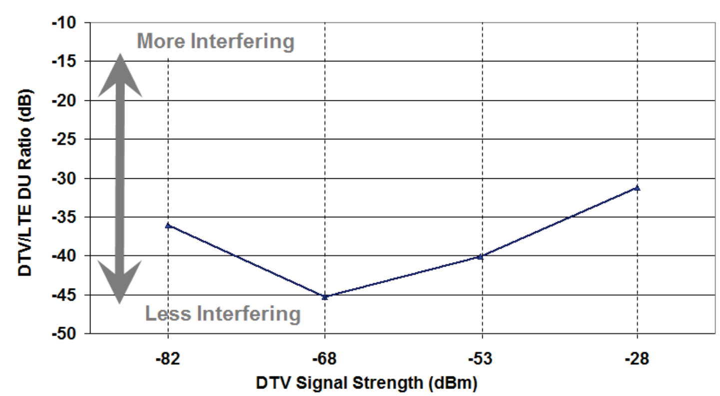


Image Impact Typically Minimal in Unlikely Event Any Interference Occurs

- All video samples below had a nearby LTE UE producing a constant transmission speed of 3.0Mbps (extremely high for uplink transmission; approximately 250% of necessary speed to upload HD streaming video, according to Skype)
- In the very rare event of any interference, degradation in signal quality is gradual, and at times, only barely noticeable; the most commonly observed impairment will be a **small pixel cluster loss**

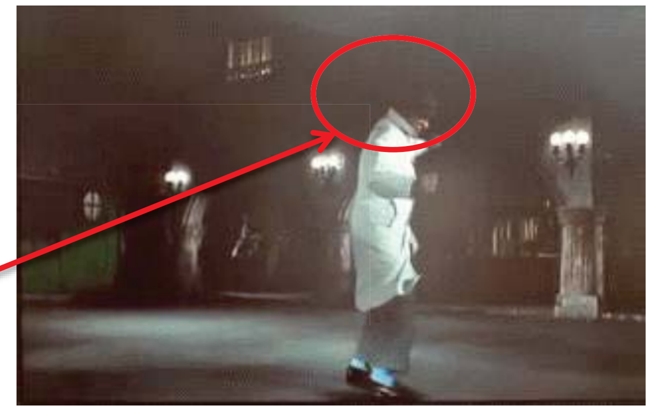
At Threshold of Visibility ("ToV")

- **Handset distance from antenna: 2.0 meters**

Clear signal

Exceeding ToV by 1 dB

- **Handset distance from antenna: 1.9 meters**



Pixel loss

Exceeding ToV by 5 dB

- **Handset distance from antenna: 1.1 meters**

Intermittent Signal loss

Exceeding ToV by 7 dB

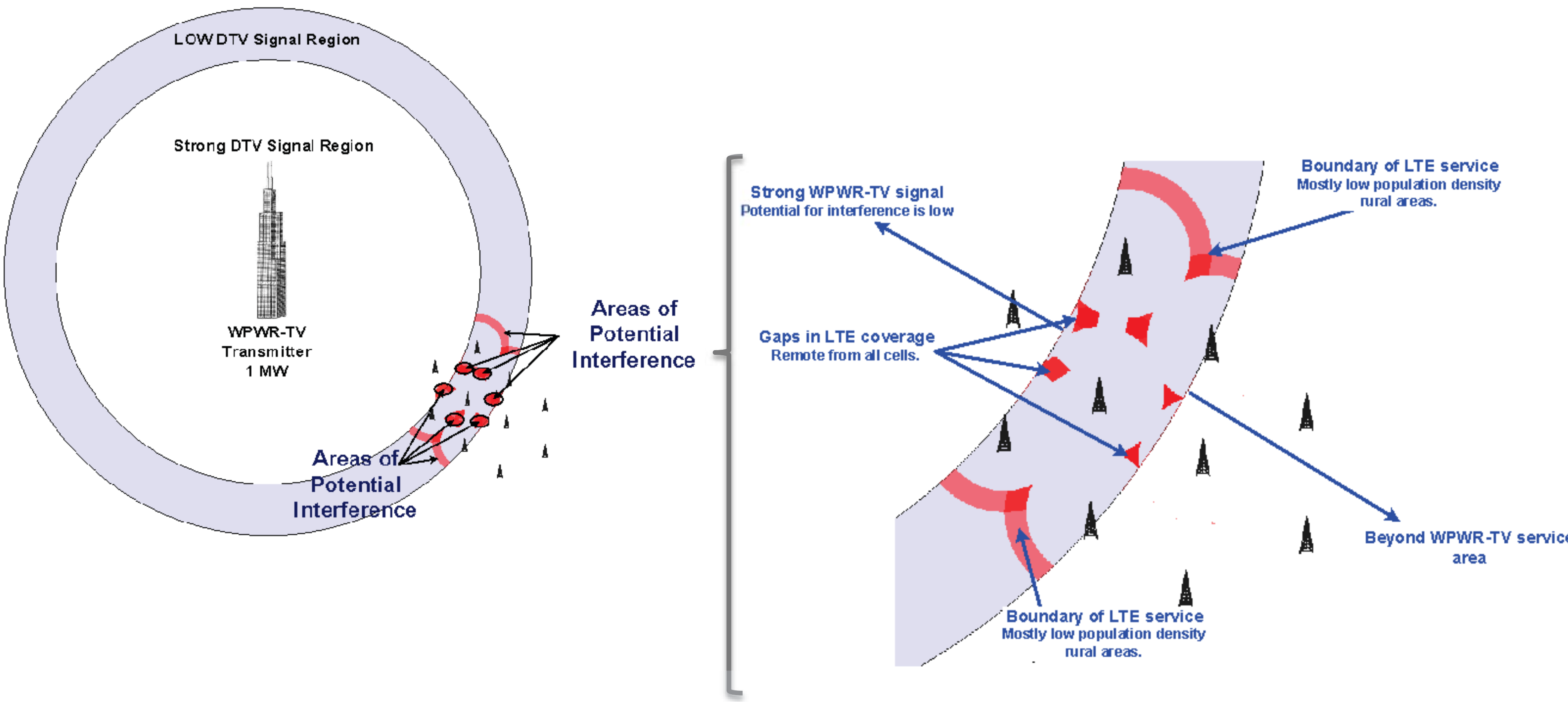
- **Handset distance from antenna: 0.9 meters**

II.

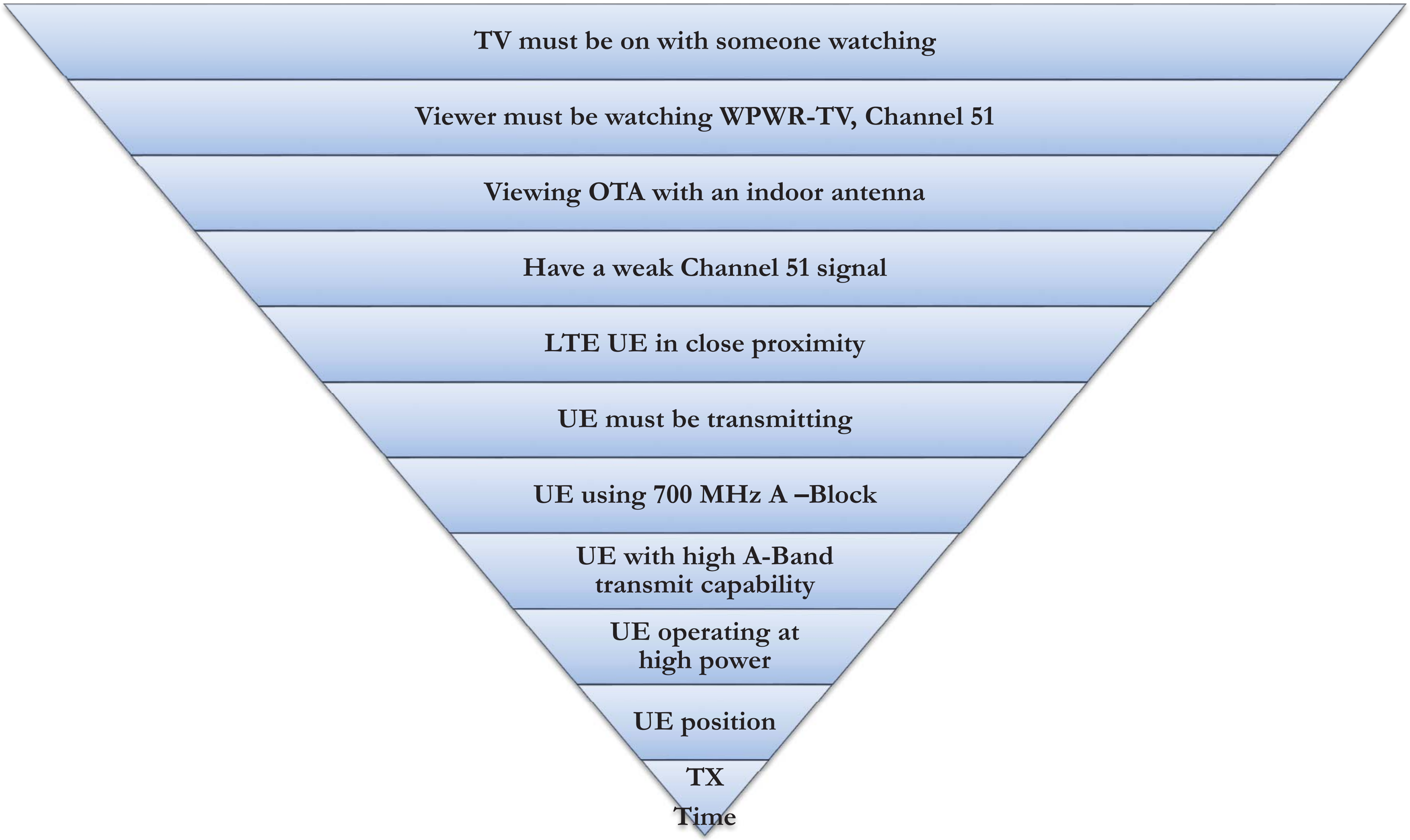
The likelihood of interference with DTV signals from LTE is remote

Illustrative Areas of Potential Interference

- **The probability of LTE to DTV interference is highest where the DTV signal is weak and the LTE UE is transmitting at its maximum power**
- **King Street Wireless' license has been authorized to operate in this highest-risk environment since 2011, with no known interference issues**
- **Probability of interference is much lower, and most often virtually non-existent, in other areas**



Probability of Interference



Quantification of Interference Impact

- **Only about 50[a] households within the addressable Chicago population have the potential for interference issues with regard to WPWR-TV**
- **This figure conservatively assumes that:**
  1. **100% of wireless devices are operating and transmitting on Band 12, AND**
  2. **No data transmissions from wireless devices are offloaded via home wi-fi connections**

Footnote	Factors Mitigating Interference	% of Population	Potentially Impacted Population	Potentially Impacted Households
1,2,8	Chicago 700 MHz A Block BEA Population Served By WPWR	100%	10,044,748	3,819,296
3	Homes that do not watch TV via cable or satellite	14%	1,386,175	527,063
4	Remaining homes using antennas	51%	703,132	267,351
	People in areas with potential for LTE UE Interference (DTV signal strength < 62.1 dBu).	10%	73,190	27,829
5	Largest Wireless Carrier Market Share	34%	24,884	9,462
6	WPWR-TV (Channel 51) PEAK measured Nielsen rating	1.3%	295	112
7	Population within 1.2km of a cell site (LTE UE transmit powers below 14 dBm)	58%	122	46
	People Who Watch WPWR-TV And May Be Impacted[a]		**122**	**46**
	People Who Could Benefit From Better Wireless Service			
	Major Wireless Carrier Subscriber Market Share	34%	**3,415,214**	**1,298,561**

Footnotes are on slide 32

(a) These 122 persons/46 households are not a static group. Instead, the composition of the group changes during the course of a day as TV viewers turn their televisions on and off, switch channels to and from channel 51, use their wireless devices, and move closer to and farther from an indoor DTV antenna while using their mobile phone.

III.

In the unlikely event of interference to DTV signals, multiple mitigation paths exist

Operator Interference Management Mechanisms

Operators of LTE networks have multiple tools to eliminate interference in specific trouble spots, if any are found

Control Traffic Placement	• Most common LTE UE transmissions are control exchanges with base station • These are normally on the edges of the band, but can be moved to reduce interference
Transmit Power Control	• An individual cell can limit the transmit power of LTE UE under its control
Wi-Fi Offload	• Wi-Fi offloading already carries 80% of data traffic from wireless devices • The vast majority of offloading is done while the consumer is at home • Wi-Fi offload is growing, and is aggressively promoted by network operators
Traffic Scheduling	• Long duration, large data uploads are already scheduled in ways that minimize interference
Ancillary Small-Cell	• Pico and femtocells can be installed in problem locations to permanently reduce the power of LTE UE transmissions in those locations

DTV Viewers have simple solutions to prevent/eliminate any interference

Immediate Remedies

Change body position or orientation of phone

- Approximately 50% of time, a user will have LTE UE positioned such that her body blocks signal from DTV antenna
- Even if LTE UE signal reaches DTV antenna, degree of cross polarization will almost always exist, reducing coupling efficiency of LTE signal into antenna

Step further away from the TV

- 70% people state that they multitask while watching television at least once a week, less than half do so daily
  - Only 15% of viewers are on phones for a show's entire duration, and the vast majority of those are using data via home Wi-Fi

Permanent Solutions

Install an alternative antenna

- Replacing outmoded antennas with current indoor antenna technology can greatly enhance reception
- Rooftop antennas significantly increase distance between LTE UE and antenna and introduce isolation via ceiling and roof

Install a low-pass filter

- Low-pass filters are currently on market which effectively block LTE signal while passing DTV signal
  - One of the easiest implemented remedies

Potential Laser Conditions Upon FCC Approval

- **To proactively address any potential issues regarding Laser not being an operator and thereby not knowing what network will be deployed or how interference will be mitigated, Laser proposes the following conditions to a potential waiver granting / approval to operate**
- **Laser is willing to bear <u>all</u> costs to eliminate interference**

Potential Conditions Upon FCC Approval

Network Conditions

- The uplink band will be used for low power LTE handsets
- The downlink band will be used for base stations
- The lower 1 MHz of the uplink band will serve as a guard band
- The network will be limited to an LTE FDD network until repacking occurs from the Incentive Auction
- A group will be set-up to receive and respond promptly to consumer complaints
- Monthly reports will be furnished to the FCC regarding any consumer complaints and how they were handled

Interference Mitigation

- At Laser 's expense, the following mitigation techniques will be provided:
  - Better indoor antenna
  - Outdoor antenna
  - Low-pass Filter
  - Femto Cell
  - Provide pay-TV (cable, satellite, IPTV) service to customers
- Potential network controls:
  - Move control signaling away from WPWR-TV
  - Use highest A-block resource blocks first

Laser / OET Agenda Recap

I. Laser test results and current operations prove de minimis interference

- These results complement and entirely support previous lab research findings (e.g., OET, Intertek, Ofcom, MSW)

II. The likelihood of interference with DTV signals from LTE is remote

III. In the unlikely event of interference to DTV signals, multiple mitigation paths exist

Appendix

Laser – Key People

Doug Hutcheson
CEO

- Previously CEO of Leap Wireless International
- Currently serves as Chairman of the Board of Directors, InterDigital and member of the Board of Directors, Pitney Bowes
- Also serves as a Senior Advisor, Searchlight Capital Partners
- B.S. in Mechanical Engineering, California State Polytechnic University, San Luis Obispo; MBA, UC - Irvine

Tim Ostrowski
SVP – Business Development

- Previously VP – Business Development, Leap Wireless International
- Formerly served as Chief Financial Officer for Verizon Public Communications Group
- B.S. in Finance, MBA, Northern Illinois University

Stephen Berger
Consultant – TEM Consulting

- Chair of several standards adopted by the FCC
  - ANSI C63.17 (47CFR15.31(a)(2))
  - ANSI C63.19 (47CFR20.19(a))
- Convener and 1st Chair IEEE Standards Coordinating Committee on Dynamic Spectrum Access Networks
- Panel co-moderator FCC-FDA Wireless Test Beds workshop

Laser – Technical Consultant Team

Dr. Paul Kolodzy

- Currently consults government and commercial customers on areas such as spectrum policy, and technology development
- Member of the spectrum management advisory committee for U.S. Department of Commerce
- Former Senior Spectrum Policy Advisor to the FCC
- Ph.D. in Chemical Engineering from Case Western Reserve University

Tom Rondeau

- Maintainer and lead developer for GNU Radio
- Consults through Rondeau Research
- Visiting Researcher at UPenn with Prof. Jonathan Smith
- Adjunct Professor at Center for Communications Research, Princeton

Dr. David Reed

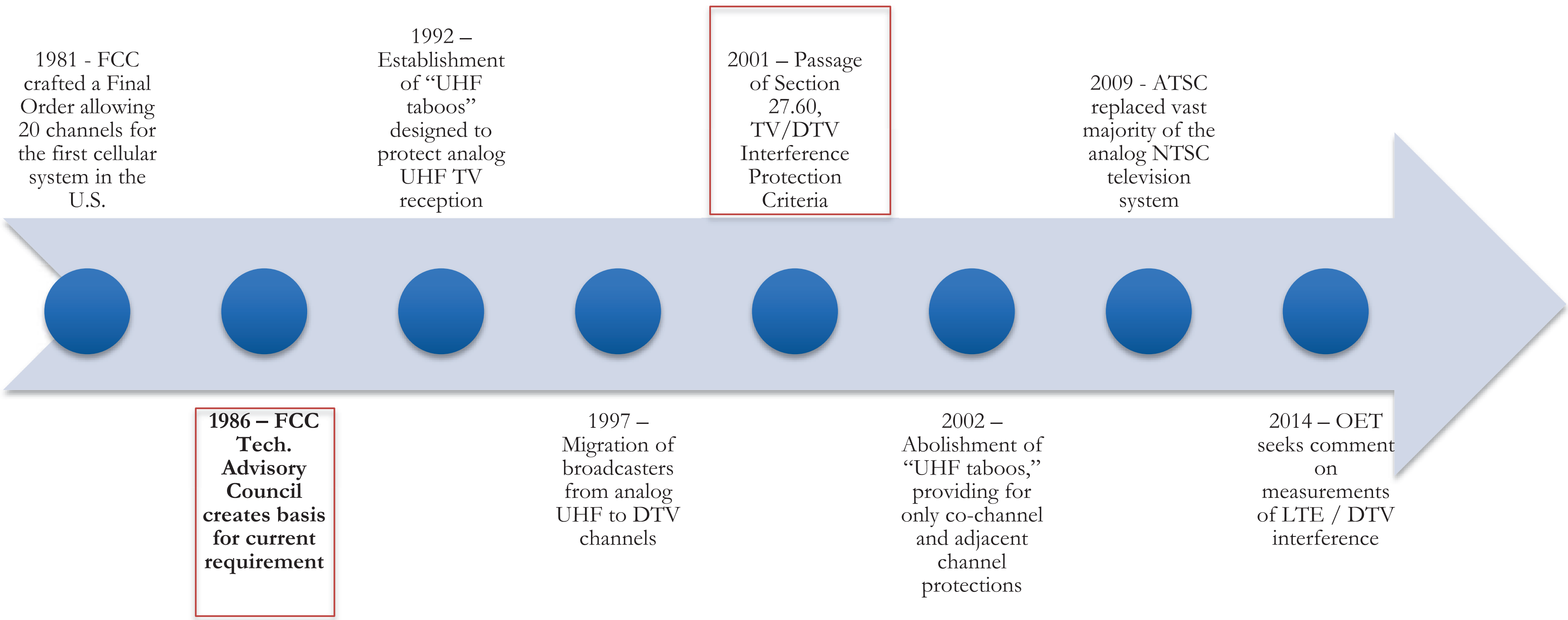
- Currently the Faculty Director of the Interdisciplinary Telecommunications Program at the University of Colorado at Boulder
- Worked for 18 years at Cable Television Laboratories, including as Chief Technical Officer and Chief Strategy Officer
- Served at the FCC as senior staff member participating in the design, technical standards and auction format of the PCS spectrum band plan
- Ph. D in Engineering and Public Policy from Carnegie Mellon University

Dr. Ken Baker

- Currently a Scholar in Residence at the University of Colorado at Boulder
- Has over 30 years experience in the wireless industry, including various positions related to RF network planning and new product research and development at both Nortel and Qualcomm
- Holds sixteen patents in wireless communication system technology
- Ph.D. in Electrical Engineering from Virginia Tech

Summary History of FCC TV/DTV Interference Policy

- **Over the past 30 years, the FCC has taken great strides to keep interference policy updated to accommodate changing technological and market dynamics**



Spectrum-Efficient Mechanisms of LTE Technology

- **LTE is significantly more efficient spectrally than prior generations of cellular technology**

Flexible Bandwidth	• Both bandwidth and transmission time are efficiently allocated to minimize usage • Most of the time the guard band will be larger because the bandwidth usage will be smaller
Transmit Power Control	• LTE UE transmission power is kept as low as possible to maximize battery life and network capacity • Recent Ofcom and CSMAC report LTE UE usually operate in the -9 dBm to -14 dBm range, far below their -23 dBm maximum
Traffic Scheduling	• LTE UE are allocated transmission time by the base station. As a result, they do not transmit a large percentage of the time • LTE uses 10 ms frames and seldom gives an LTE UE the full frame; significant off times even during high data rate transmissions
Variability of Transmission Patterns	• Most user activities require only small uplink data transmissions • There is a well known disparity between uplink and downlink traffic
Varied Modulation & Coding States ("MCS")	• LTE supports multiple MCS; channel conditions allow up to 64 QAM • Higher MCS mean more data is sent in a shorter time
Wi-Fi Offload	• Whenever possible, LTE offloads large data transmissions to Wi-Fi • Currently ~80% of wireless device data is offloaded to Wi-Fi

Assumptions and Footnotes for Slide 20

1. The population for Chicago and the areas with potential or no LTE interference were based on the 2010 census
2. The area used to calculate the population is based on standard FCC F(50,90) dipole-adjusted DTV Threshold contour in the viewing area for WPWR-TV
3. Chicago cable/alternate delivery systems was based on Nielsen data for February 2015
4. Homes using antennas were 7% of population based on Consumer Electronics Association July 2013
5. Wireless Carrier market share was the highest for any carrier shown nationally by Statista in 3rd Quarter 2014
6. WPWR-TV rating based on Nielsen data for calendar year 2013 and applied to estimated TV homes in Chicago of 3,477,250 as defined by Nielsen
7. Devices used by people within 1.2 Kilometers of a cell site do not transmit at power levels that would cause DTV interference based on March 2015 in-market tests; 58% per 2010 census
8. There are 2.63 people per household in Illinois per the 2010 census

DTV Receiver Chipsets by Generation

First generation chip sets, 1998. Could only compensate for reflections ("ghosts") between -3/+20 uSec, and at least 3 dB weaker than the direct signal.

Second generation chip sets, 1999. The ghost compensation range was unchanged, but the chip set went from 3 to 2 integrated circuits, with reduced footprint and power requirements.

Third generation chip sets, 2000. The ghost compensation range was increased to -3/+44 uSec, and slightly stronger ghosts, of no more than 2.5 dB weaker than the direct signal, could be accommodated. This generation still used two ICs.

Fourth generation chip sets, 2002. The ghost compensation range was increased to -10/+44 uSec, and even stronger ghosts, of no more than 1.5 dB weaker than the direct signal, could be accommodated. This generation still used two ICs.

Fifth generation chip sets, 2005. Ghost compensation range of ±50 uSec, and ability to accommodate 0 dB (same amplitude as direct signal) ghosts. This generation used only one IC, for both 8-VSB and QAM.

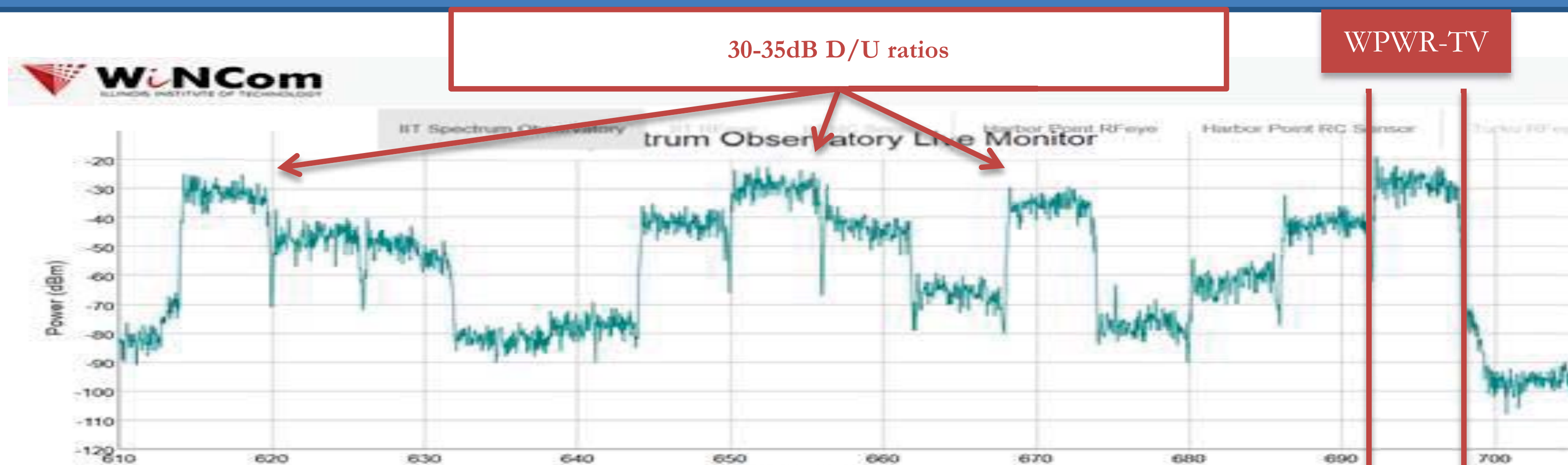
Sixth generation chip sets, 2007. Ghost compensation range of ±73 uSec, and ability to accommodate 0 dB reflections; ATSC A/74 "compliant." This generation used only one IC, both 8-VSB and QAM decoding supported.

Source: Intertek report

The UHF Band in Chicago is Very Crowded

- **DTV channels often operate with 30 and 35dB D/U ratios from adjacent stations**

South of Downtown Chicago (3300 South Federal Street)



North of Downtown Chicago (Harbor Point, IL)