

Greenwood Telecommunications Consultants LLC

Lessons Learned from the LightSquared/GPS Proceeding

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Stanford SCPNT Conference

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Topics...

- Our experience
- Why this happened
- Current status
- GNSS L1: will it remain a “quiet neighborhood”?
- FCC said this was an “anomaly”. True? Avoid repeating history?
- Positive insights, lessons learned from estimated millions spent
- A few recommendations

*“Things that are done, it is needless to speak about...
things that are past, it is needless to blame”*

Confucius

Experience: Perhaps Like a Tow Truck Operator We Attempted to Salvage, Overhaul LSQ Spectrum Plan...

After the spectrum “collision”, LightSquared (LSQ) retained us for its “GPS Issue”

- Our Task: Solve; if solutions exist, now or later, tenably available to either side
- Our condition: Advocate no harm to GPS signal reception or GPS services
- Provided independent engineering analyses, tests
- Early 2011: Asked to join FCC TWG
- Headed Cellular TWG Sub-Group and ExCom/NTIA Cellular tests
- Lastly, originated alternative plan to launch LSQ in shared Federal spectrum
- Alternative: Share (not clear) the 1675MHz NOAA GEOS/Radiosonde Weather Band.
 - Currently under review by NTIA, NOAA, LSQ
 - Affords LSQ a 20x20 LTE solution, in phases
 - Lever TWG and NTIA/ExComm test results
 - Long term: Salvage “Lower 10” spectrum, once and if cleared

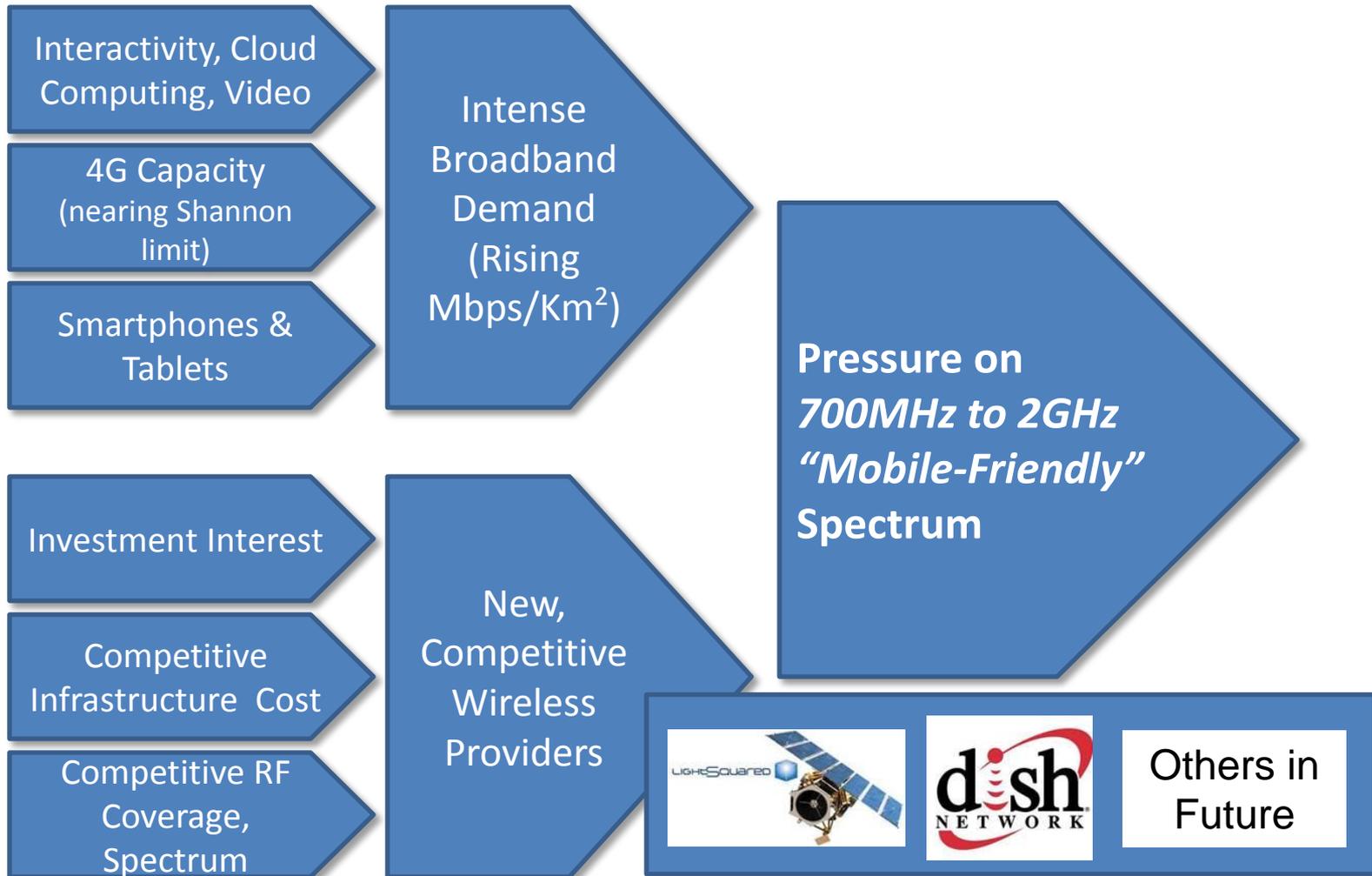


Our View: For LSQ/GPS Compatibility Many Changes Were Required

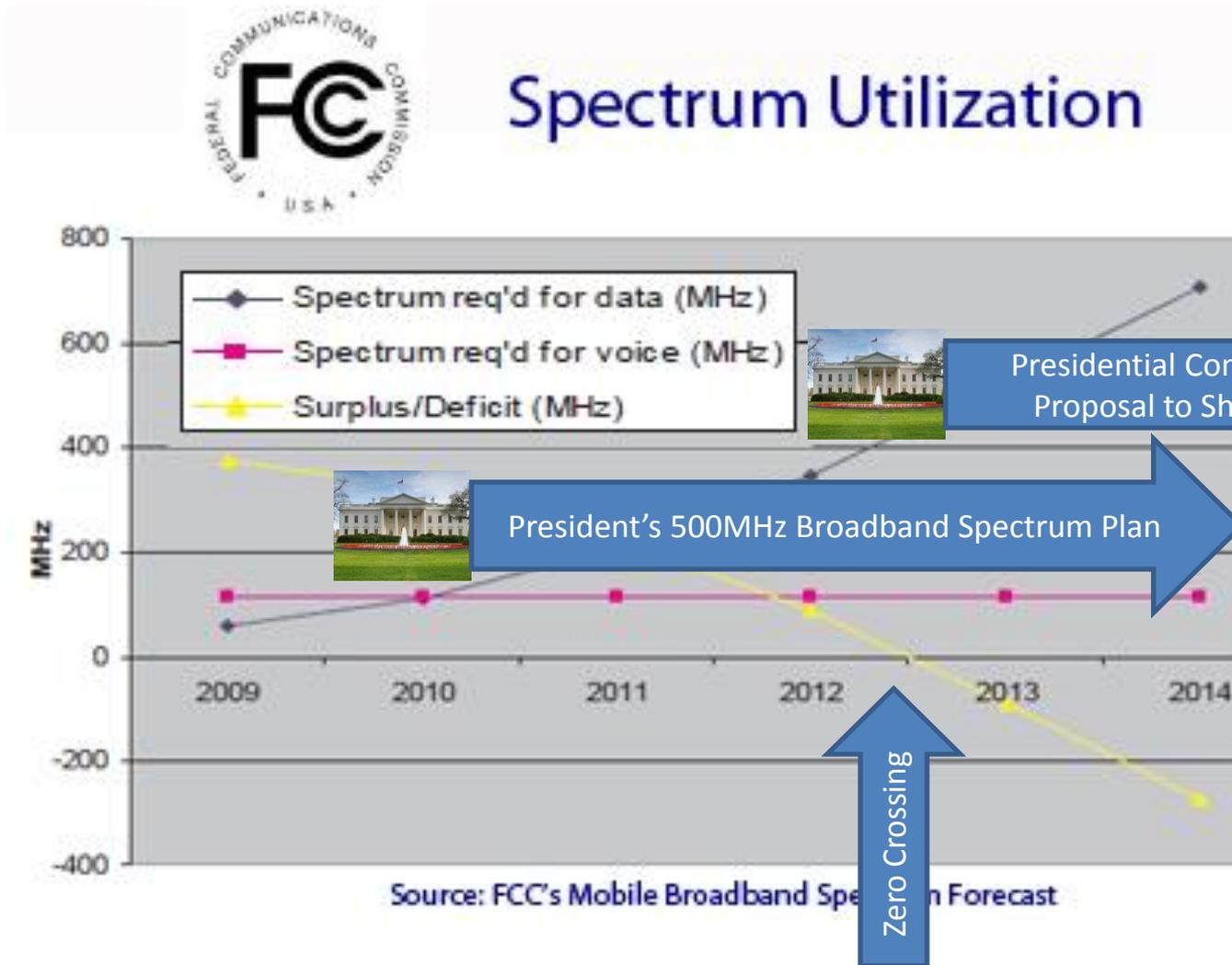
Number of Recommendations :

- Abandon the two downlink frequency plan (to eliminate possible IM3 spur on 1575MHz)
- Abandon “Upper 10” 1545-1555MHz operation, even femto (instead, seek equitable spectrum credit)
- Drop 15kW EIRP operation. Impractical, unnecessary (network is mobile up-link limited anyway)
- Airport exclusion zones: If full EIRP, 1 mile minimum (banked-flight analytical scenarios, Lower 10)
- “Power on the Ground:” Limit the base station emission *additionally* to P_{incident} to 1 uW, or -30dBm
- Based on TWG results, -1 dB C/No appears to be harmful interference threshold (particularly General Navigation, High Precision) unless alternative exists (e.g., Cellular 3GPP/3GPP2, Aviation RTCA/ICAO).
 - TWG Cellular report: Results used a similar -1dB condition, applying 3GPP performance, thresholds.
- “Pivot spectrum”: LTE launch spectrum elsewhere, given time to make GPS compatible
- High Precision GPS: Determine design options to be immune to *future* “Lower 10” LTE base stations
 - Assess field upgrade paths available
 - Assess readiness in presence of neighboring L Band terrestrial MSS, AWS signals
- (Post-LSQ) Made similar GPS comments in the DISH Network FCC S-Band proceeding (May 2012):
 - Set OOBE-into-GNSS for a 1m separation. Recommended OOBE into GNSS be set to -105 dBW/MHz.
 - Recommend compliance be uniform across cellular CMRS bands and devices.

Why Happened: Demand for *Mobile* Broadband Rising, Causing More Crowded Spectrum Landscape



FCC Economists' Forecast Mobile "MHz Deficit" by 2013



FCC Moving from Transmit to Transceiver Regulatory Regime

Transmit-Centric

- Dominated first ~100 years of radio
- Focus: Interference *at the transmitter*
- Profile: High power transmitters, large service areas, limited collocations, circa 25 kHz channels except for broadcast
- Seemingly ample spectrum
- Interference cost >> Spectrum cost
- Spectrum treated as almost free good
 - Broadcast spectrum grants
 - TV “White Spaces”
 - Dedicated government bands
 - Dedicated private use bands, etc

Transceiver & Spectrum-Centric

- Focus: More interference avoidance *at the receiver*
- Profile: Lower transmitter power, highly collocated, close range, high spectral purity transmitters, efficient and wider bandwidth (e.g., 10MHz LTE) channels
- Spectrum cost > Interference cost
- Compatibility made across entire bands (e.g., harmonize down-, uplinks with neighbor’s down, uplinks) (**Issue:** GNSS, RNSS are *non-transceiver* based)
- International bodies such as 3GPP addressing spectrum compatibility (e.g., sets band specific specifications, certain receiver performance specifications)
- Forecast: Spectrum sharing regulations will come

Growing Awareness: “Receiver Protection” Standards

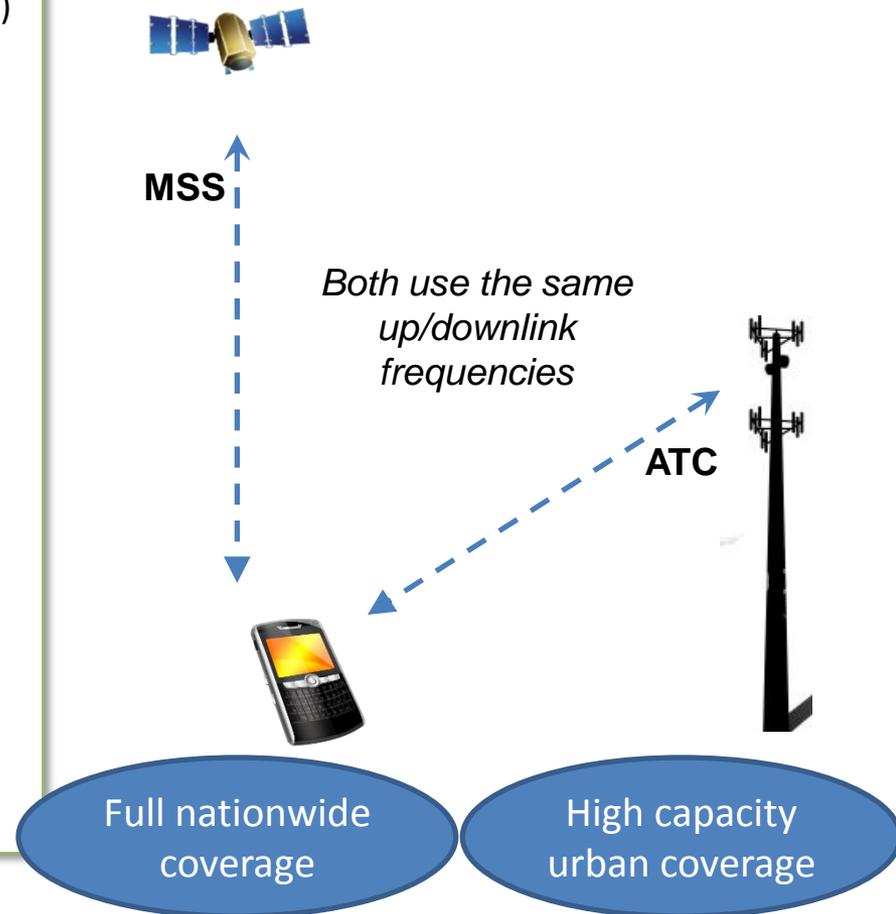
“Improvements in wireless receivers are also essential, so we can place services more closely together on the spectrum chart without interference,” FCC Chairman Julius Genachowski told an audience at the Wharton school of business earlier this month.

Although the idea for receiver standards has been around a long time, the concept was infused with new life during the brawl last year over LightSquared’s proposal to build a high-powered wireless broadband network.

Source: Inside GNSS, “RTCA on Path to Study RF Interference Limits and Tougher GNSS Receivers”, Dee Ann Divis, October 16, 2012

LSQ's "Two-Fer" Spectrum Innovation: Mobile Satellite+ ATC, "Auxiliary Terrestrial Component"

- ✓ Evolves from pure Mobile Satellite Service (MSS)
- ✓ Belief: Cellular network on steroids
- ✓ One "giant cell" in the sky with conventional metro, urban powerful cells on ground
- ✓ Belief: New entrant can enjoy virtually "day-one" nationwide coverage
- ✓ Belief: Relatively rapid deployment of urban coverage with 3/4G capacities, coverage
- ✓ Much more than a "gap filler"; no traffic "cap" (see FCC ATC 2005 Modified Order)
- ✓ Spectrum "two-fer": Re-uses same down-and-up-link frequencies very economically...
- ✓ FCC staff economist: \$12B value for ~ \$1B investment (FCC internal memo, 9/16/2009)

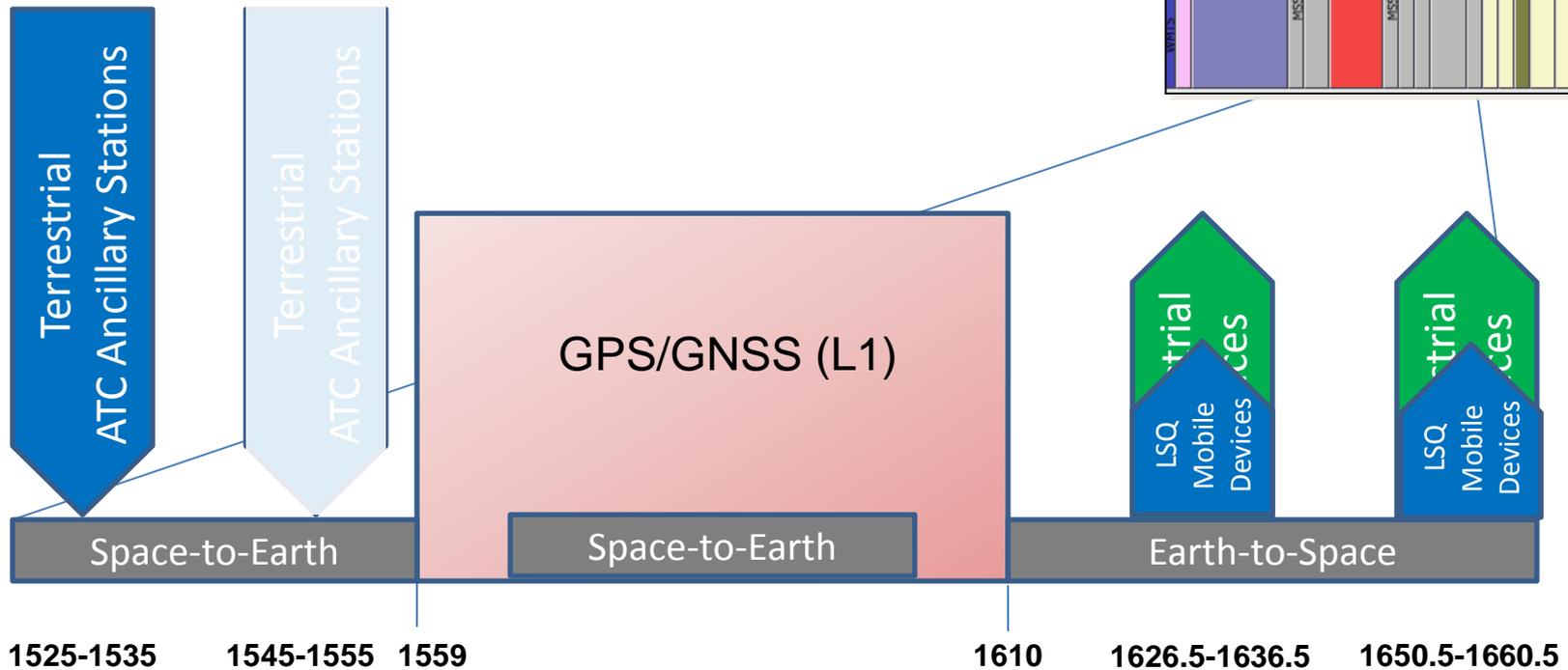
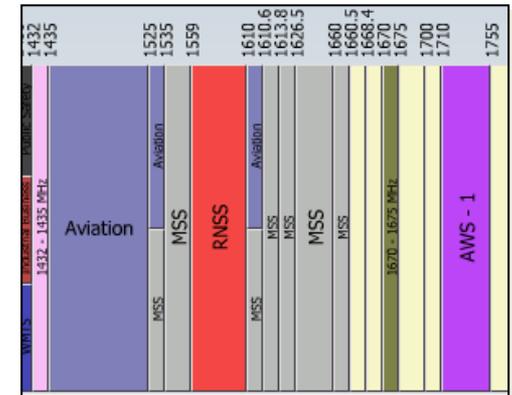


GNSS L1 was a “Quiet Neighborhood” ...

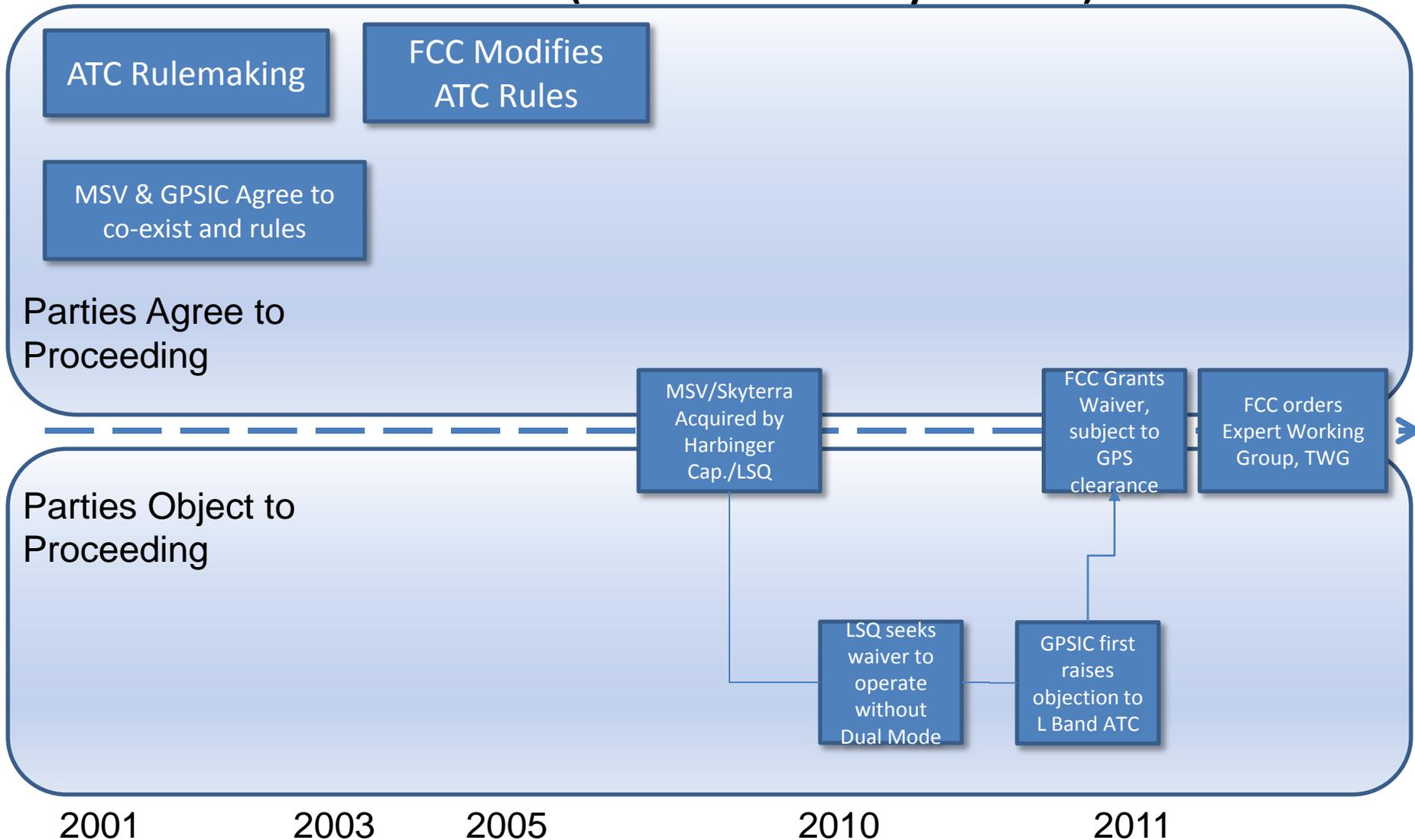
but Mobile Satellite terrestrial devices, usage plus “ATC” raise “next door” signal power substantially

Even without the “Upper 10” ATC base stations

FCC Table of Frequencies



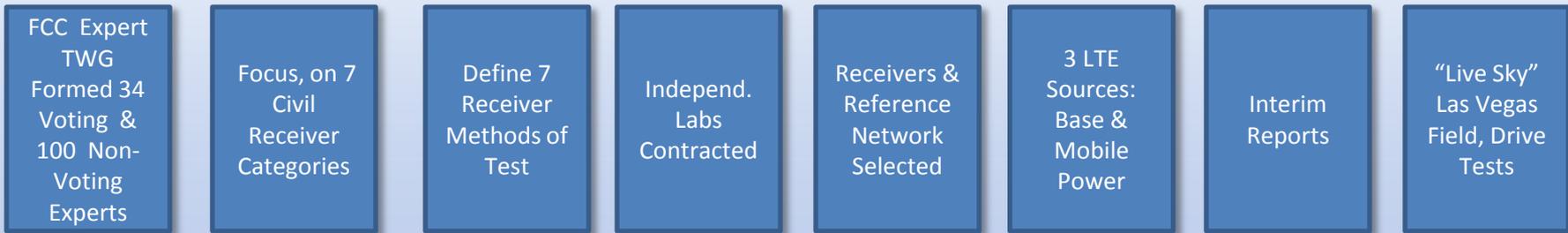
Timeline (2001 to Early 2011)



Note: MSV is SkyTerra predecessor

Timeline (2011- 2012)

Parties Agree



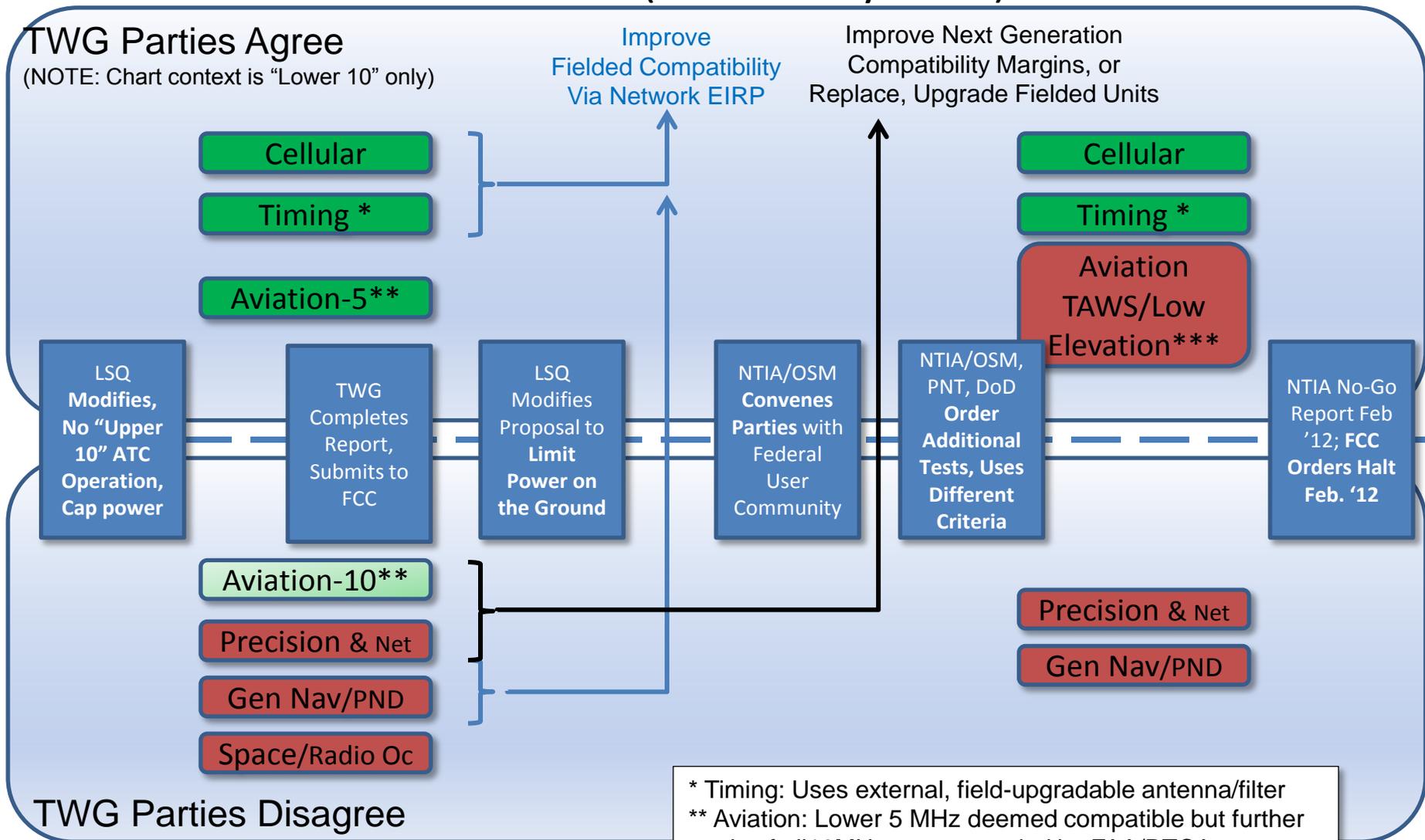
FCC Praises TWG Efforts, Implores Solutions

Parties Disagree



First Half 2011 →

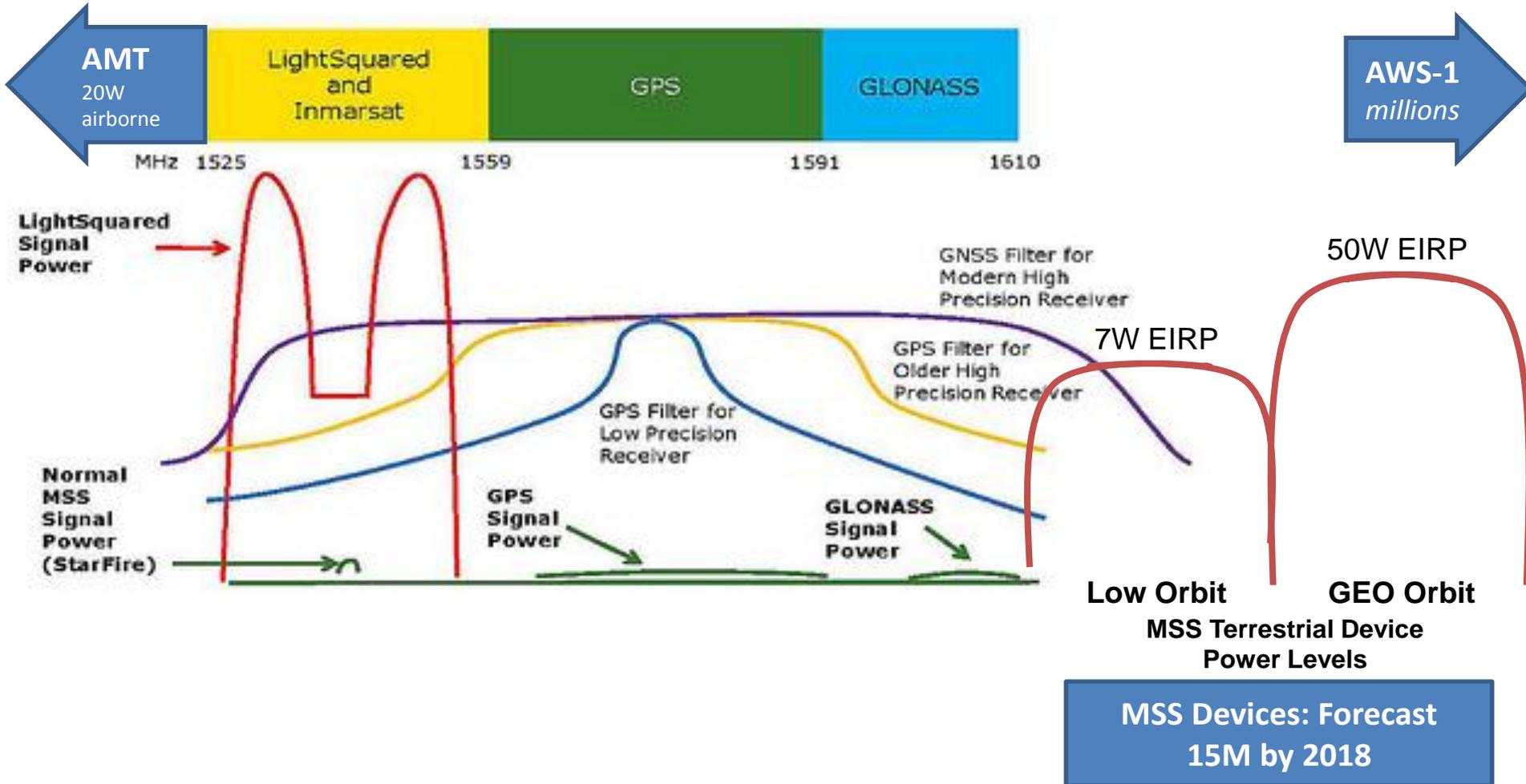
Timeline (2011- Early 2012)



* Timing: Uses external, field-upgradable antenna/filter
 ** Aviation: Lower 5 MHz deemed compatible but further study of all 10MHz recommended by FAA/RTCA
 *** Aviation/TAWS not presented during TWG; case only surfaced, analyzed in Q4 2011.

Are Precision Receivers L-Band Neighbor Ready?

Current "Older" Precision today face issues; "Modern" Precision Must Develop More Immunity



GPS High Precision Adjacent L-Band Compatibility Study

Presented, Published at ION ITM January 2012

Maintaining Precision Receiver Performance while Rejecting Adjacent Band Interference

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BIOGRAPHIES

Eric Derbez earned his PhD in Mathematics from McMaster University (Ontario). He has worked at eRide, Inc, NavCom/John Deere, RX Networks, Inc., and now works as an embedded software and technology consultant with Greenwood Telecommunications Consultants and others.

Christopher Kurby earned a BSEE from University of Illinois in Champaign Illinois and holds a Masters in Electrical Engineering and a Masters of Engineering Management from Northwestern University. He previously worked for Motorola since 1973 in radio communications design with his last position in the Chief Technology Office of Motorola Mobility. He holds 32 US patents, and serves as Technology Partner at Greenwood Telecommunications Consultants.

Richard Lee has a 37 year career in wireless communications, and more recently, assisted GPS systems companies starting as an RF engineer with Motorola Communications Sector in 1973 and later cellular service providers, US WEST/Air Touch, PrimeCo

Motorola's Direct Digital to RF Conversion radio transmitter architecture. He received his BSEE and MSEE degrees from the Illinois Institute of Technology and holds over 20 US patents. He currently serves as Senior RF/Microwave Engineer at Greenwood Telecommunications Consultants.

ABSTRACT

This paper addresses precision GPS receiver design criteria, and balancing receiver performance requirements to raise immunity for existing and new terrestrial receivers. This paper provides results and descriptions of simulation, testing methods, and lab test data based on commercially modified precision receivers that were developed to create compatible operation with a range of neighboring L Band terrestrial devices or services. This includes both *existing* services such as MSS uplink, cellular AWS and aeronautical telemetry, and recently proposed new L Band services, specifically ATC cellular networks (generally designated by the ITU as Complementary Ground Component, or CGC).

INTRODUCTION

Objectives:

1. Verify compatibility design feasibility
2. Assess re-design, field upgrade cases
3. Test with LSQ Lower 10, 1630MHz mobile signals (conducted)
4. Test past/future policy assertions:
 - Is “ATC Gap Filler” operation accurately claimed to mitigate harm to GPS?
 - L Band neighbors: HP GPS compatible?
 - Other reasons (beside LSQ) to raise compatibility globally, or within the US?
 - Practical to field retrofit?
 - Modernized GPS version receivers: Are these a good vehicle to redesign, raise L Band compatibility?

GPS High Precision Compatibility Tests

Test Summary:

- Respond to claims that “Lower 10” fix not at hand or too difficult to achieve
 - Group delay variation impact was believed most critical
- Three major brand high precision GPS receivers tested
 - Several manufacturers also submitted results to FCC using an independent lab sponsored by LSQ
- Applied two LTE interference sources: Lower 10 and closer 1626.5-1636.5 uplink int. signals
- Air cavity (used as a BAW filter proxy) and Ceramic filters tested. (7 poles, 21MHz 1/2BW)
- Increase adjacent band filter selectivity after first active stage(s); if inadequate try more aggressive alternatives
 - Latter step proved unworkable

Conditions, Criteria:

- Constellation: Spirent multi-band generator
- Conducted in screen room; assures testing isolated from external RF sources
- Hot, Cold, Room ambient temp.
- Test cases: With & without RTK (from Spirent)
- Primary comparative criteria:
 - Assess changes in receiver C/No degradation
 - Assess changes in reported 2D position error
 - Measurement noise floor: ~0.25mm (with RTK)
- Report degradation versus interference versus each LTE signal present
- Later tests:
 - Multipath (Spirent)

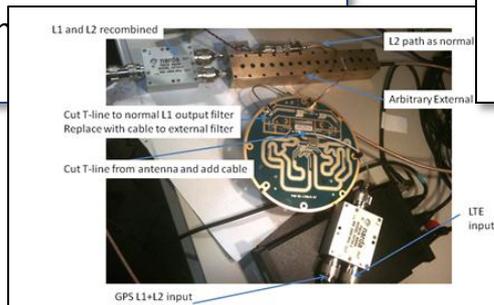


Figure 35. Major Brand front end modified after inserting combined LTE band reject and image rejection filter in L1 signal path

entation
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GPS High Precision Adjacent L-Band Study (Q4, 2011)

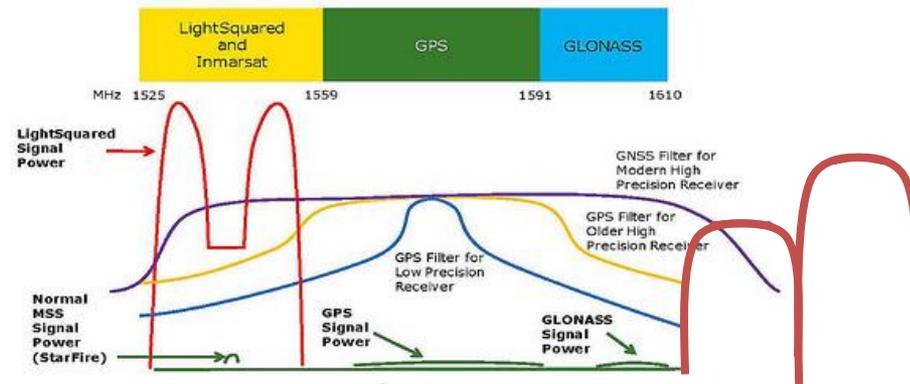
Results:

- “Lower 10” LTE susceptibility improvements attained
 - Improved susceptibility from ~ -70 to -75 dBm to ~ -10 to $+11$ dBm
 - Adequate for proposed LTE operations: 20 dB margin for “Lower 10”
- Ample margin for Mobile “UE” uplink (1626-1660MHz) rejection
 - Allows “modern” 1m separation between MSS, LSQ mobiles and GPS receivers
- Simple, feasible upgrades available – place upgraded filter after first active stage(s)
 - More complex group delay variation (GDV) compensation appears unnecessary
- New BAW filters potentially add to traditional ceramic, air cavity options:
 - BAW excellent for low GDV, high Q, environmentally rugged, small size
 - BAW requires volume to supply components cost effectively

GPS High Precision Adjacent L-Band Study (Q4, 2011)

Policy Question Findings:

- **“ATC is only a gap filler” argument – tests proved invalid**
 - ATC interference impact occurs at minimal (1%) duty cycles
- **L1 “Quiet neighborhood” no longer accurate, especially with wider GNSS receivers:**
 - Millions of MSS, AWS devices coming, both potential adjacent or OOB E interferers
 - 7W MSS can affect precision GPS up to 10km away (-1 dB C/No)
 - GNSS means wider RF front-ends, increases adjacent band impacts
- ***Takeaway: Regardless of LSQ, do for global customers’ receiver L Band compatibility***



Stanford SCPNT Presentation
November 2012

Lesson #1: Perhaps Wisdom in Mr. Falcone's *Recent* Stmt.

“[LightSquared lead investor, Phil] Falcone, a Harvard grad and former professional hockey player, acknowledges it was a mistake to have cold-shouldered the GPS industry when problems first arose.

“We should have reached out and tried to do it in a more amicable fashion, as opposed to going in and saying they're wrong, it's their problem, they should spend the money to fix it,” he says.

“We tried to bully—not bully, but push our way through.”

Bloomberg Business Week

May 3, 2012

Lessons Learned Recommendations

Adopt GNSS Receiver Protection Standards (RPS)

- We're in a close and crowded world.
- Broadband + GNSS devices can be few meters apart
- Today, FCC Part 15 shields customers' interference liability, appropriate?
- RPS conformance & certification seems a better way to balance regulators', vendors', and customers' receiver fitness for use requirement

Rulemaking Process Needs Attention; Stakes Today are Much Higher

- FCC: This case was "an anomaly". Beg to differ -- this problem was knowable.
- Adjacent band interference (ABI) is consequence of spectrum crowding.
- 2001-05 attention was probably on OOB following UWB/GPS, no/little ABI scrutiny.
- Common sense: First test, show, verify all interference modes.
- Ensure non-transceiver services specially evaluated, protected.
- Interference uniformity, avoid making incremental rules
 - This shifts burden unduly on to newer spectrum entrants

Lessons Learned Recommendations

GNSS Spectrum Advocacy: Raise User & International Representation

- Vendors, DoD, US Government obviously important, but who pays?
- Users, customers pay if receiver interference limits their practical usage
- ITU, 3GPP, other multi-stakeholder, international bodies seem a good model here
- User groups have expert insight about their operating, thus interference environment
- Recent FCC Ex Parte by National Society Pro. Surveyors: “NSPS emphasized the need to test this proposed plan before issuing any new license modification to LightSquared.” (Major user group if involved likely could have weighed in decade ago)
- International: New constellations, wider bandwidth signals & 3-4 more carriers expand the depth of thorough interference analysis

NTIA, PNT EXCOM Implementing GPS Spectrum Compatibility Measures



SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL EXECUTIVE COMMITTEE

JAN 13 2012



The Honorable Lawrence E. Strickling
Assistant Secretary for Communications and Information
U.S. Department of Commerce
Washington, DC 20230

Dear Assistant Secretary Strickling:

At the request of the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA), the nine federal departments and agencies comprising the National Space-Based Positioning, Navigation and Timing (PNT) Executive Committee (EXCOM) have tested and analyzed LightSquared's proposals to repurpose the Mobile Satellite Services (MSS) frequency band adjacent to Global Positioning System (GPS) frequencies to permit another nationwide terrestrial broadband service. Over the past year we have closely worked with LightSquared to evaluate its original deployment plan, and subsequent modifications, to address interference concerns. This cooperative effort included extensive testing and analysis of GPS receivers. Substantial federal resources have been expended and diverted from other programs in testing and analyzing LightSquared's proposals.

It is the unanimous conclusion of the test findings by the National Space-Based PNT EXCOM Agencies that both LightSquared's original and modified plans for its proposed mobile network would cause harmful interference to many GPS receivers. Additionally, an analysis by the Federal Aviation Administration (FAA) has concluded that the LightSquared proposals are not compatible with several GPS-dependent aircraft safety-of-flight systems. Based upon this testing and analysis, there appear to be no practical solutions or mitigations that would permit the LightSquared broadband service, as proposed, to operate in the next few months or years without significantly interfering with GPS. As a result, no additional testing is warranted at this time.

The EXCOM Agencies continue to strongly support the President's June 28, 2010 Memorandum to make available a total of 500 MHz of spectrum over the next 10 years, suitable for broadband use. We propose to draft new GPS Spectrum interference standards that will help inform future proposals for non-space, commercial uses in the bands adjacent to the GPS signals and ensure that any such proposals are implemented without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs.

ASHTON B. CARTER
EXCOM Co-Chair
Deputy Secretary of Defense

JOHN D. PORCARI
EXCOM Co-Chair
Deputy Secretary of Transportation

Current Process Reported:

- Seek consensus position within Federal, DoD groups
- NTIA/OSM generating receiver standard & L Band EIRP emission specifications
- Public comment cycle
 - Federal Register, possible later this year
- NTIA to present mask & protection recommendations to FCC
- FCC likely initiates NPRM cycle

Lessons Learned Recommendations

“Upper 10”: Candidate for Ground Augmentation?

- LSQ publicly abandoned *operating* in the “Upper 10” (1545-1555 MHz)
- Question: Sound alternatives for this band? (Including as a good GNSS guard band)
- Consider: Sub-microwatt uses for short range range augmentation, such as DOT ITS
- TWG findings: Given very low EIRP, ample compatibility with Precision GPS nearby...
 - Precision GPS: -82 dBm worst case Upper 10 susceptibility (-1 dB C/No)
 - 1 uW EIRP transmitter is about 13 dB below at 1 meter
- Seems suitable for high availability in urban areas; provides urban in-fill, redundancy such as Intelligent Transport Systems (ITS) systems
 - At 100m range: Signals \sim -135 dBm incident power at an ITS receiver antenna
- Band continues as a Space-to-Earth downlink, shared with GEO-MSS services, including carriage of GPS/GNSS corrections (OmniSTAR™, Starfire™)