L Band Service Compatibility
Part I: Optimum OOBE Compatibility

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Discussion

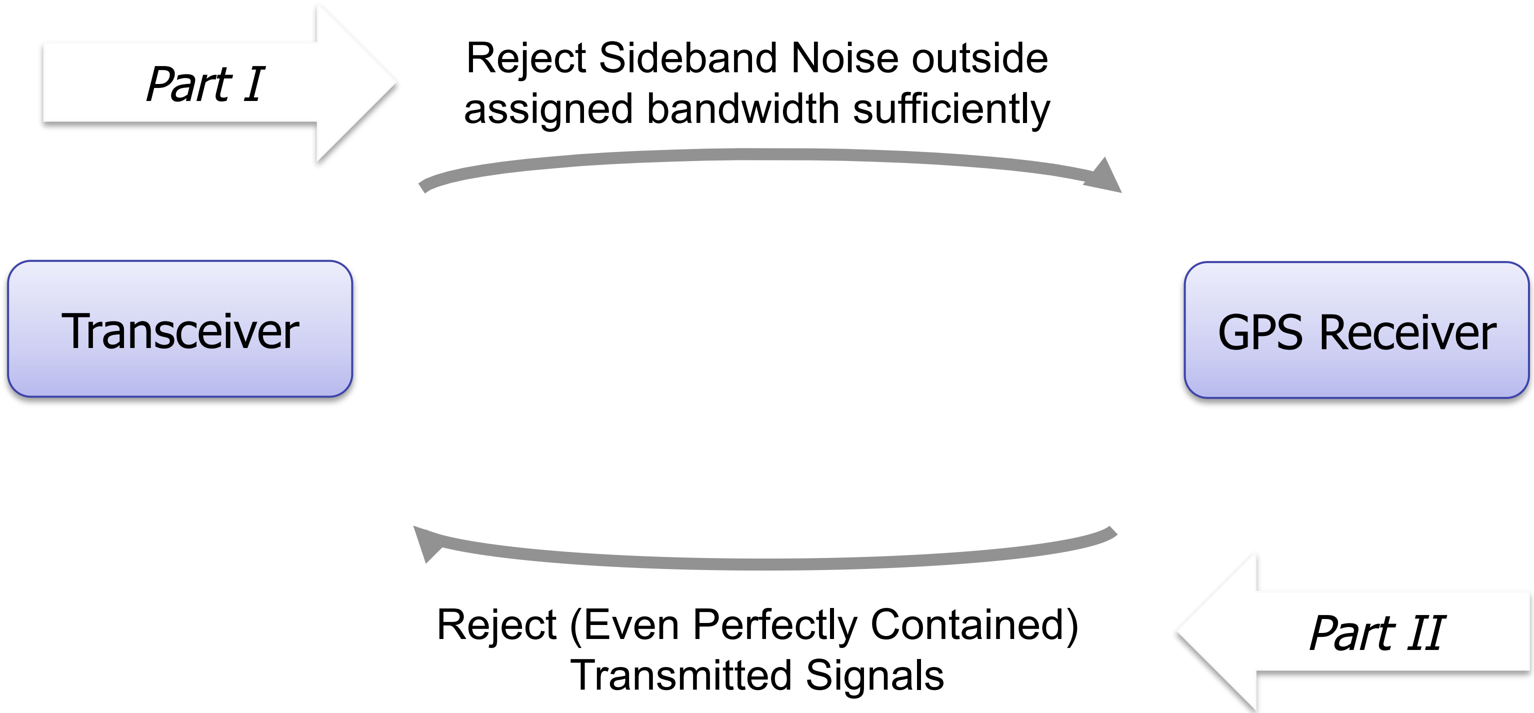
- Two Parts
  - Today we focus on optimum L Band ABC Out of Band Emission into GPS L1, OOBE.
  - Next ABC meeting will examine GPS-side mitigation of Adjacent Band Interference, ABI.

- Greater Compatibility: OOBE and ABI are distinct but parallel forms of interference
  - OOBE mitigation governed by transmitter's sideband emissions into GPS receive bands
  - ABI rejection governed by GPS receiver rejection of nearby lawfully operating signals
  - Parallel: Must solve, set OOBE and ABI rules together

- We start with the first compatibility factor, OOBE…
  - From any band, but special focus on L Band, Proposed ATC inside GEO-MSS uplink
  - Presented in our FCC Request for Comments filed September 2013
  - We find that ATC offers optimum level of compatibility at -105 dBW/MHz using competitive commercial components
  - We also examine compatibility criteria and compare MSS vs ATC uplink OOBE impact

OOBE & ABI Cross Parallel Paths…

Dense Compatibility Requires Acting on Both Receiving and Transmitting Entities to Reject Even a "Quiet" Neighbors' Undesired Signals

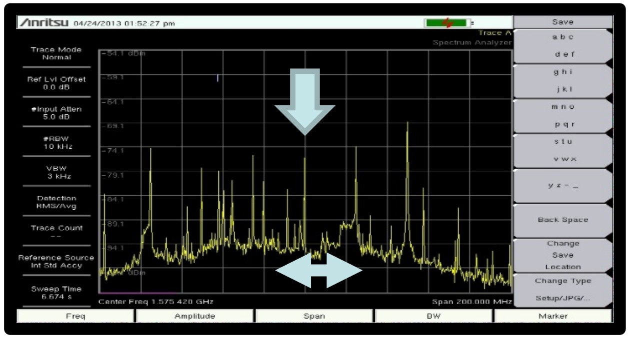


Object is to have Transceiver and GPS Receiver Harmlessly Operate One Meter Apart based on Standards

Difficult History to Coordinate Spectrum Compatibility

Yet GPS & Broadband Have a Common, Growing Customer Base

- Diverse systems -- compatibility is the toughest
- GPS/LS controversy obviously well known
- However, disputes not new among different spectrum "neighbors"
- Sometimes its not always just adjacent neighbors
  - Uncontrolled OOBE may arise inside the same band
  - Examples:
    - Latest European Pseudolite proposals
    - Non-radiating device OOBE (e.g., Part 15)



Broadband & GPS *Interaction* compels a different analysis

- If LS terrestrial station downlinks now moved…
- And, AWS-3 auction again proving high value of mobile
- GPS, Broadband customers now extensively overlap
- So, no longer about one side's "spectrum trespassing"
- Its increasingly about satisfying customers who use both services, at the same time

GPS Suppliers

- Most Affected (TWG)
- GLN
- Precision
- Non-certified Aviation (GLN)
- Network

Broadband Services

- Closer Transmissions
- PCS, Cellular
- Unlicensed 2.4 GHz
- MSS Next Gen
- **L Band ATC**
- AWS-3, AWS-1
- AMT

Common Customers

- On or in-vehicle usage
- Driverless vehicles?
- Metro to rural coverage
- IoT, M2M, Vehicle tracking
- Future GPS+BB apps

Transmitter OOBE Compatibility Analysis

GPS Receiver Impact Criterion: 1dB Degradation of C/No

Analysis:

1. Use 1m separation, which in part is based on a settled 3GPP standard
2. First test a single, then multiple device cases

Determination of OOBE for 1dB loss in GPS C/No		
GPS RX noise figure	2	dB
GPS Rx noise floor	-172	dBm/Hz
Power allowed for 1dB C/No loss	-178	dBm/Hz
Gain of GPS antenna (From TWG report)	-5	dBi
Body blockage	2	dB
Free Space Path loss at 1 m (1575MHz)	36	dB
OOBE EIRP allowed at Tx	-135	dBm/Hz
OOBE EIRP allowed at Tx dBW/MHz	-105	dBW/MHz

Adds to receiver kTF noise → Power allowed for 1dB C/No loss

3GPP standard separation → Free Space Path loss at 1 m (1575MHz)

Resulting OOBE budget → OOBE EIRP allowed at Tx dBW/MHz

Notes:

1. Assumes OOBE products within primary lobe of CA code, centered at 1575.42MHz
2. OOBE threshold impact measured at receiver LNA = -178dBm/Hz
3. 90% of cellular antennas tested gain < -5dBi over the hemisphere by the TWG
4. Precision antennas were also found to have -5dBi gain at the horizon b y the TWG

This analysis returns a single receiver OOBE value of -105 dBW/MHz. We examine feasibility to deliver this later based on commercially available mobile product components.

MSS versus ATC OOBE Protection Distance

Single MSS/ATC Mobile Transmitter, Free Space Path Loss Between Devices for 1 dB C/No degradation

-70 dBW/MHz
(MSS)

-95 dBW/MHz

-105 dBW/MHz

Protection distance = 56 m
(not drawn to scale)

Protection distance = 3 m

Protection distance = 1 m

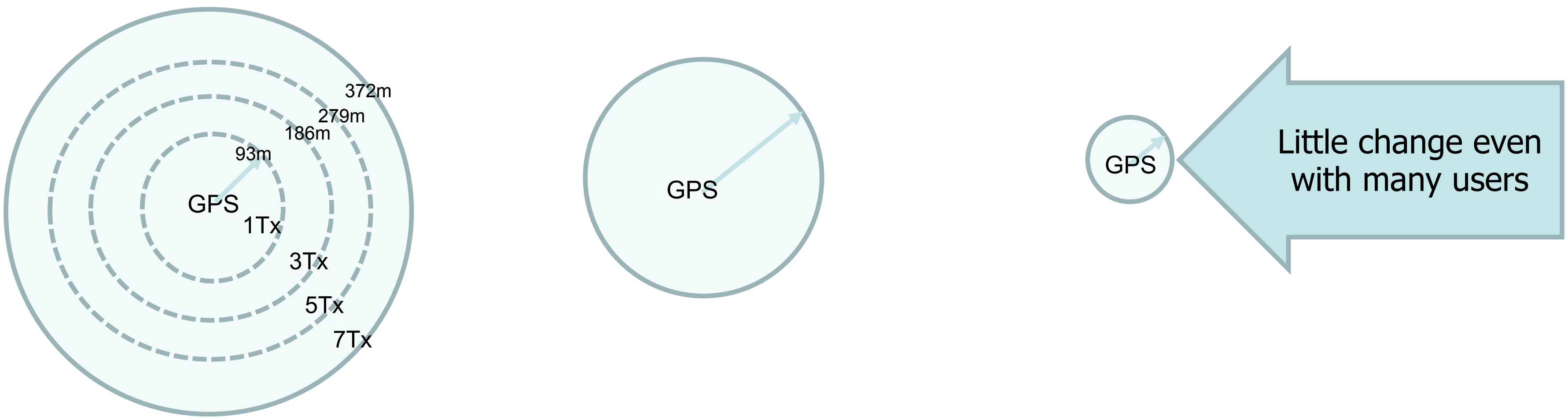
MSS versus ATC OOBE Protection Distance

Multiple mobile case*, User density and Minimum protection distance for 1 dB C/No degradation

-70 dBW/MHz (MSS)

-95 dBW/MHz

-105 dBW/MHz



Protection unit d=93m
Density 0.004 ATC/100sq m

Protection unit d=5.2m
Density 1 ATC/100 sq m

Protection unit d=1.6 m
Density 11 ATCs/100 sq m

- -70 dBW/MHz results unacceptable, yet part of current rules
- -95 dBW/MHz at d=5.2m for some use cases excessive
- -105 dBW/MHz at d=1.6m shows robust compatibility with surrounding devices

* Notes:

- Assumes all mobiles transmit at the same time
- GPS interference harm criterion of -1dB C/No
- OOBE energy relates to products that falls within CA code main lobe centered at 1575.42MHz

OOBE Commercial Feasibility

- Methodology
  - Two possible analytical approaches
    - Determine OOBE by "Forward engineering" (Used by manufactures)
      - Start from known component performance, work toward an OOBE result or objective
      - Assumes known performance of all components and interactions, e.g. PA IM
    - Or, determine by "Reverse engineering"
      - Given an end-performance objective, work backward to determine margins between major component performance levels
      - Determine Tx OOBE based on derivations of component performance information

- Basis of Mobile Components and Interactions
  - Selected 3GPP Band 25 (PCS+G) to model low Tx to Rx duplex frequency pass band separation
  - Use the commercial Avago Technologies ACMD 6125 duplex filter as a model
    - Similar technology Avago GPS/GNSS band pass filter (used commonly in cellular) production component simulation in FCC in LS ex parte proceeding showed similar rejection characteristics
    - Similar frequency separation, configuration to that proposed for LS NOAA DL/MSS ATC UPL
  - Determine Tx noise floor by duplex filter attenuation
  - Based on proposed ATC UPL transmitter operating between 1626.5-1660.5MHz
  - Scale model duplexer response (BW) and with Tx noise determine GPS protection levels

Reverse Engineering-ATC Mobile Tx/Rx Duplex Filter

Provides an Important Part of OOBE into GNSS Band

OOBE Tx Budget

Scenario	Value	Units	Comment
Rx Noise figure	6	dB	Near Minimum
Rx noise floor for 3GPP	-168	dBm/Hz	
Noise rise	1	dB	
Noise allowed from Tx 1dB deg	-174	dBm/Hz	6dB below noise floor
Rejection from duplexer*	50	dB	Min Attenuation at +80MHz
Noise from Tx allowed before filter	-124	dBm/Hz	
Noise from Tx allowed before filter	-64	dBm/MHz	
Noise from Tx allowed before filter	**-94**	dBW/MHz	

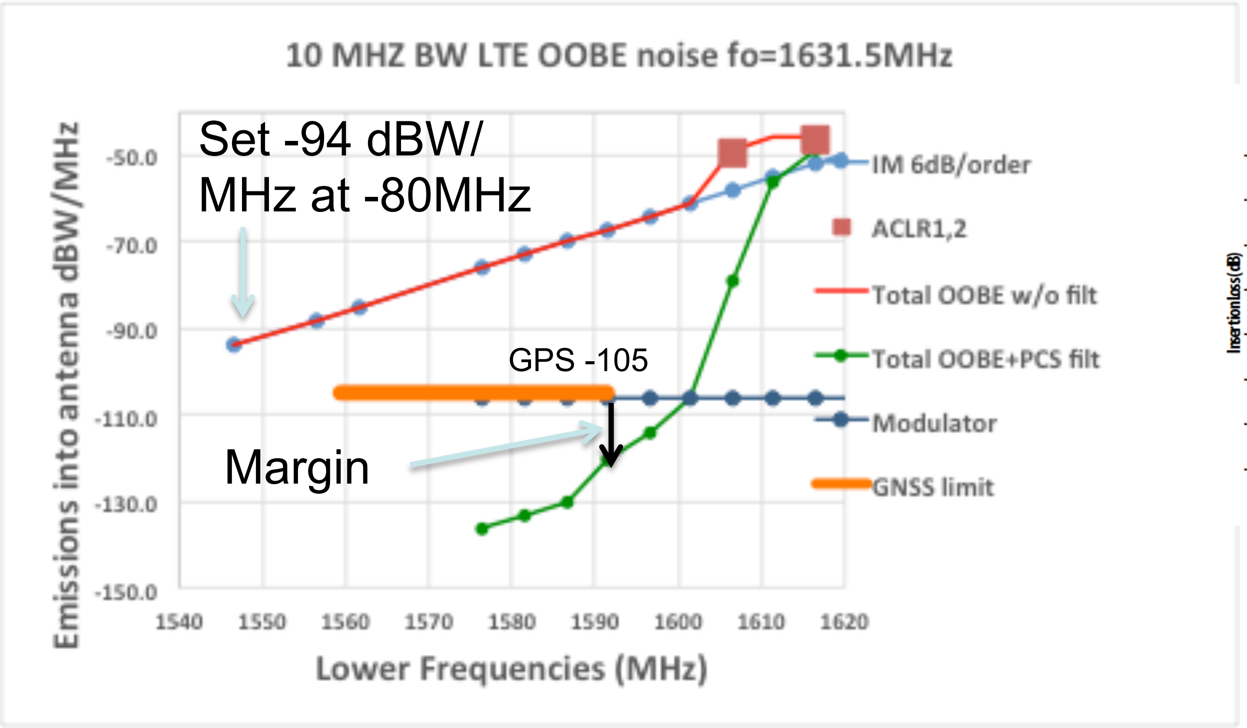
Only need 11dB attenuation to Tx noise at GNSS

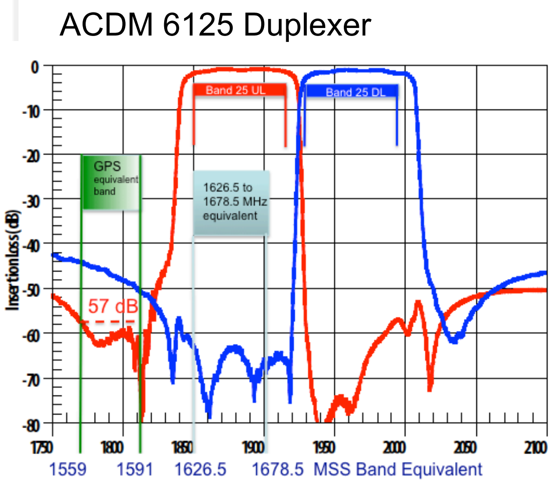
Note: Lower Antenna gains and efficiency<100% will also reduce OOBE radiated

* Minimum Rejection of 50dB at 15MHz separation based on similar design of PCS L Band Duplexer
Reference commercially available Avago Technologies 6125 Duplexer datasheet

ATC Mobile OOBE Noise Estimation

Based on 3GPP Band 25 10MHz LTE Uplink



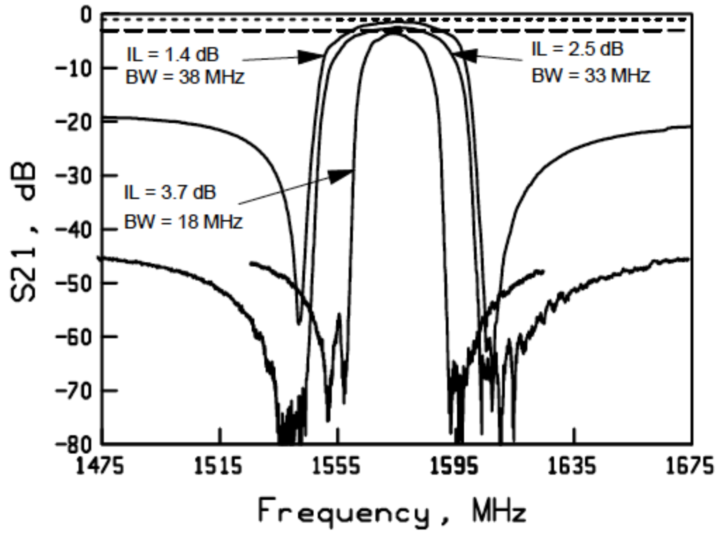


- AVAGO ACDM 6125 duplexer shifted to 1626.5MHz
- ACDM 6125 provides >50dB attenuation at equivalent GPS frequency of 1590 (-35MHz) more at 1575
  - 80 MHz Tx/Rx duplex separation based on 3GPP Band 25 for LTE ACLR to model sideband noise (OOBE) output
- OOBE dominated by PA IM and is symmetrical over +/- Δ f
- OOBE of -105dBW/MHZ is reached at 1600MHz
- This is conservative since does not include additional handset antenna loss (negative gain)
  - Handset antenna will also have less gain at GPS than ATC uplink frequencies

Duplexer Passband Loss Trade-Off

Is there an Insertion loss penalty for ATC UPL Filters Protecting GPS?

- FBAR/BAW preferred or optimal technology between 1.5 to 3.5 GHz
- Filter pass band loss dependencies
  - Increases as BW ratio is reduced
    - IL ~ BW1/BW2
  - Increases as rejection/number of resonators increases
- Actual datasheet data:



Band	Filter	BW (MHz)	T to R band (MHz)	Tx IL typ (dB)	IL w/c +85C band edge	Reject at Rx (dB)
GPS	Avago LS July 2011	55	NA	1.25	<3	>50 at 1626.5
Band I	ACMD-7614	60	190	1.4	2.1	50
PCS+G	Avago ACMD 6125	64.5	15	**1.2**	4	50
PCS	Avago ACMD 6102	59	20		2.5	55
PCS	Avago ACMD- 7403	59	20	1.4	2.7	44
LTE III	Avago ACMD-6103	75	20	1.4	3.5	50

Conclusions:

- With separation of 15 MHz between pass and reject frequencies, typical insertion losses are virtually the same as wider BW and reject bands configurations
- Since GPS at least 35 MHz below 1626.5 MHz pass band, the Insertion loss factor is not an issue