# SFNs for HD Radio

## Synchronizing the IBOC Signal

Design, Implementation and Field Trials

# Presentation Overview

1. Single Frequency Networks Today
2. Application Areas
3. Establishing SFN Planning Parameters
4. Matching D/U Signal Ratios to Signal Delay
5. Nautel SFN Implementation (FM and HD)
6. Field Trial: KUSC, Los Angeles

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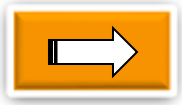
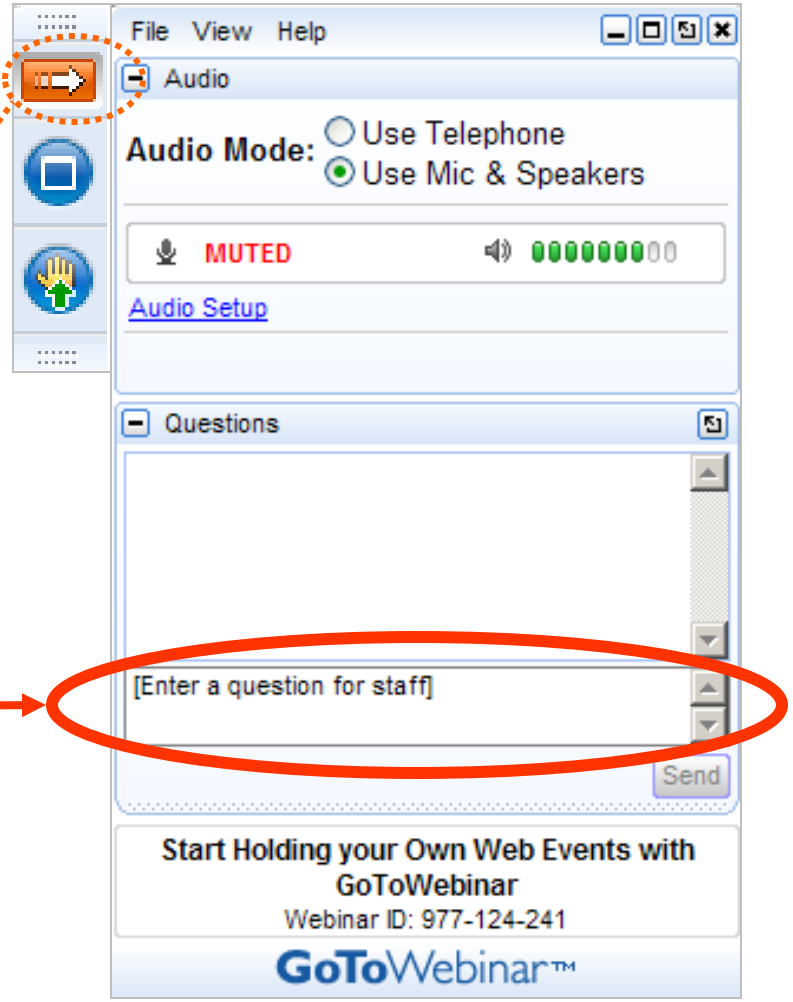
**Research Engineer**

# Questions?

*Click on*  *to open/close webinar panel*



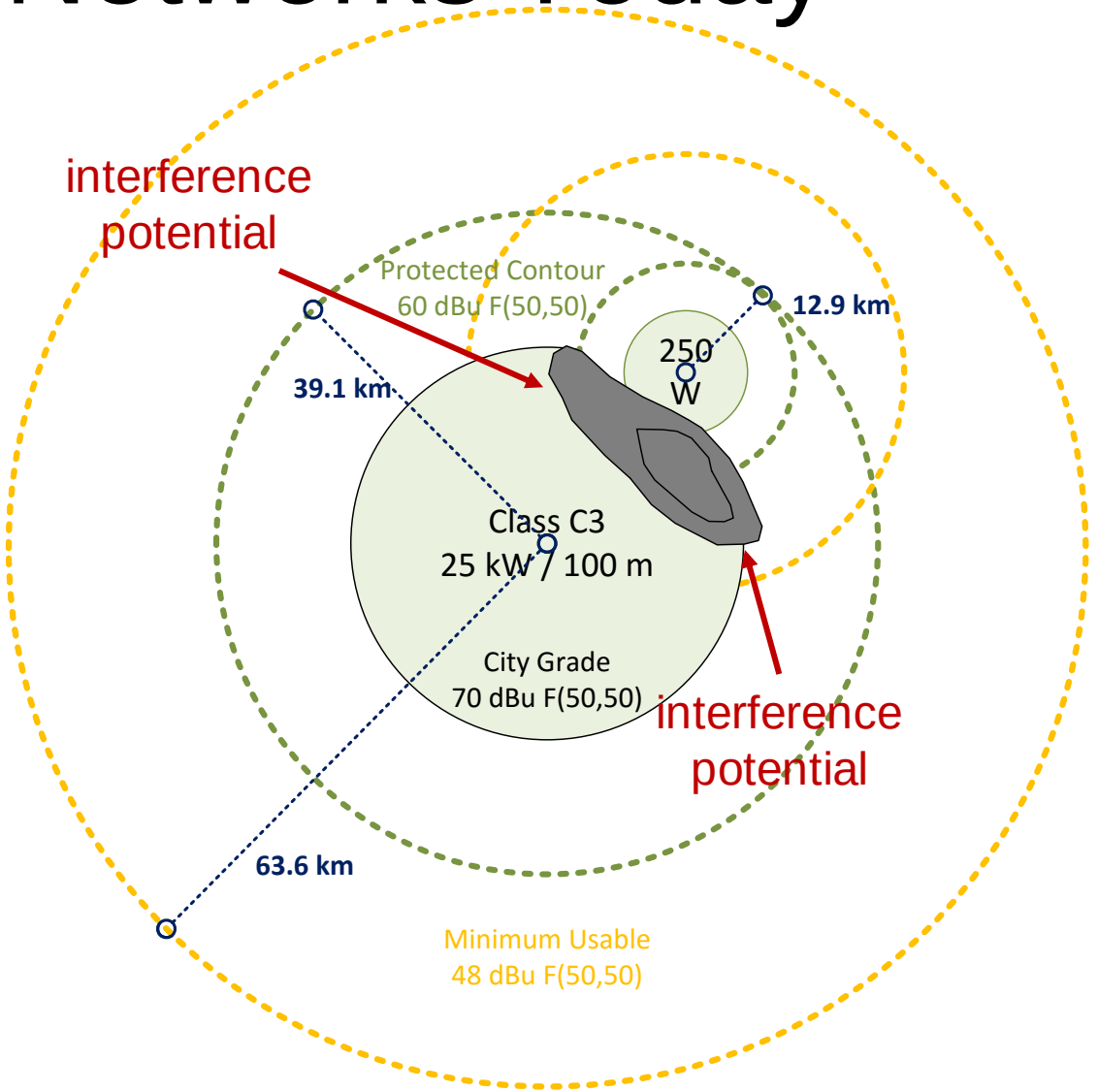

*Enter questions here*
*…then press* **Send**

# FM Single Frequency Networks Today

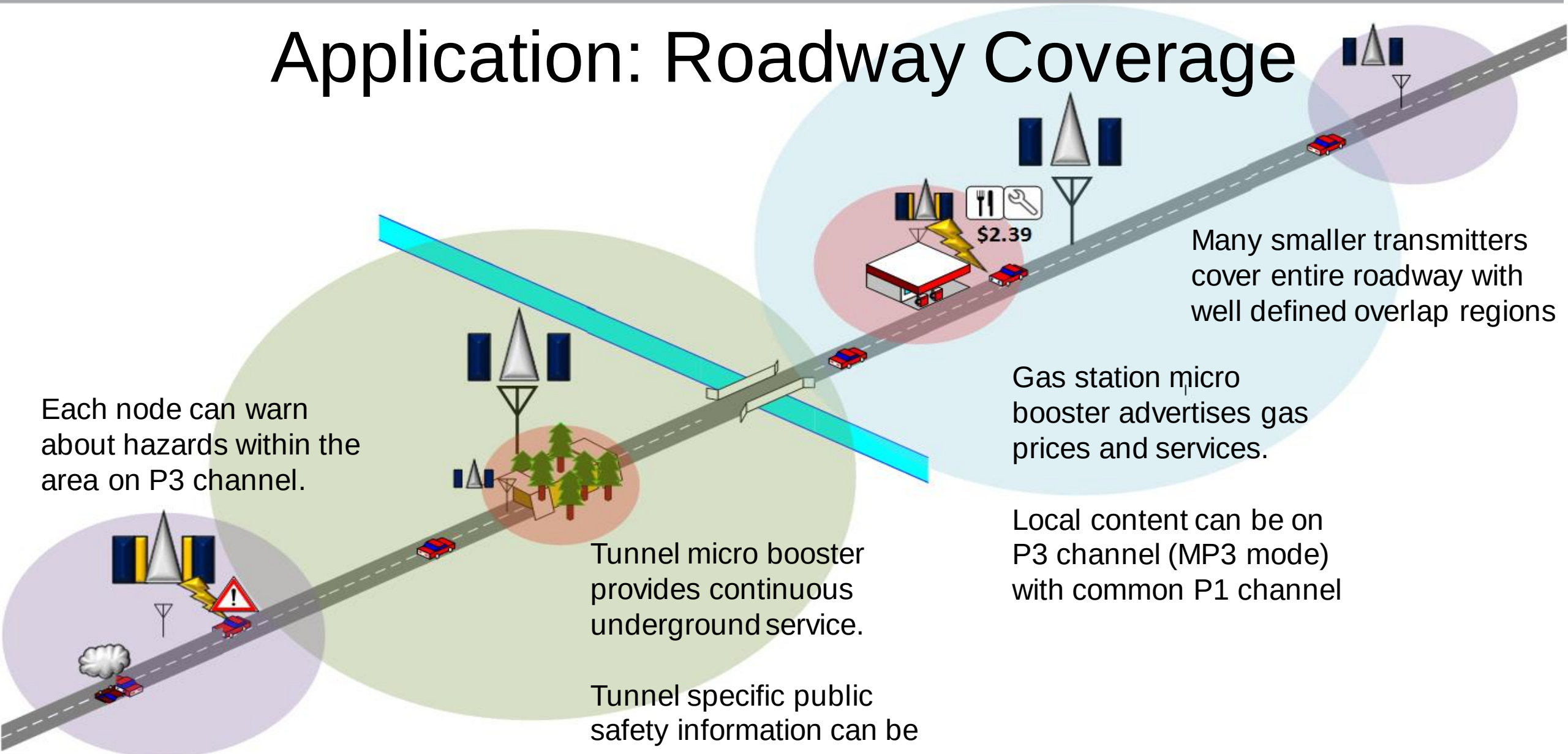
- **FM Booster stations** are **"fill-in" translator stations** on the **same** frequency as the main station by the FCC.
  - Booster contour may not exceed the protected F(50,50) service contour of the primary station.
  - Boosters maximum ERP is 20% of primary station's class
  - A primary FM station may have more than one booster.
  - Booster stations may not cause interference to reception of the primary station's signal within the community of license

https://www.fcc.gov/media/radio/fm-translators-and-boosters

  - While this example is US specific, other have similar regulations. Check with your local regulator for more info.



# Application: Roadway Coverage




Many smaller transmitters cover entire roadway with well defined overlap regions

Gas station micro booster advertises gas prices and services.

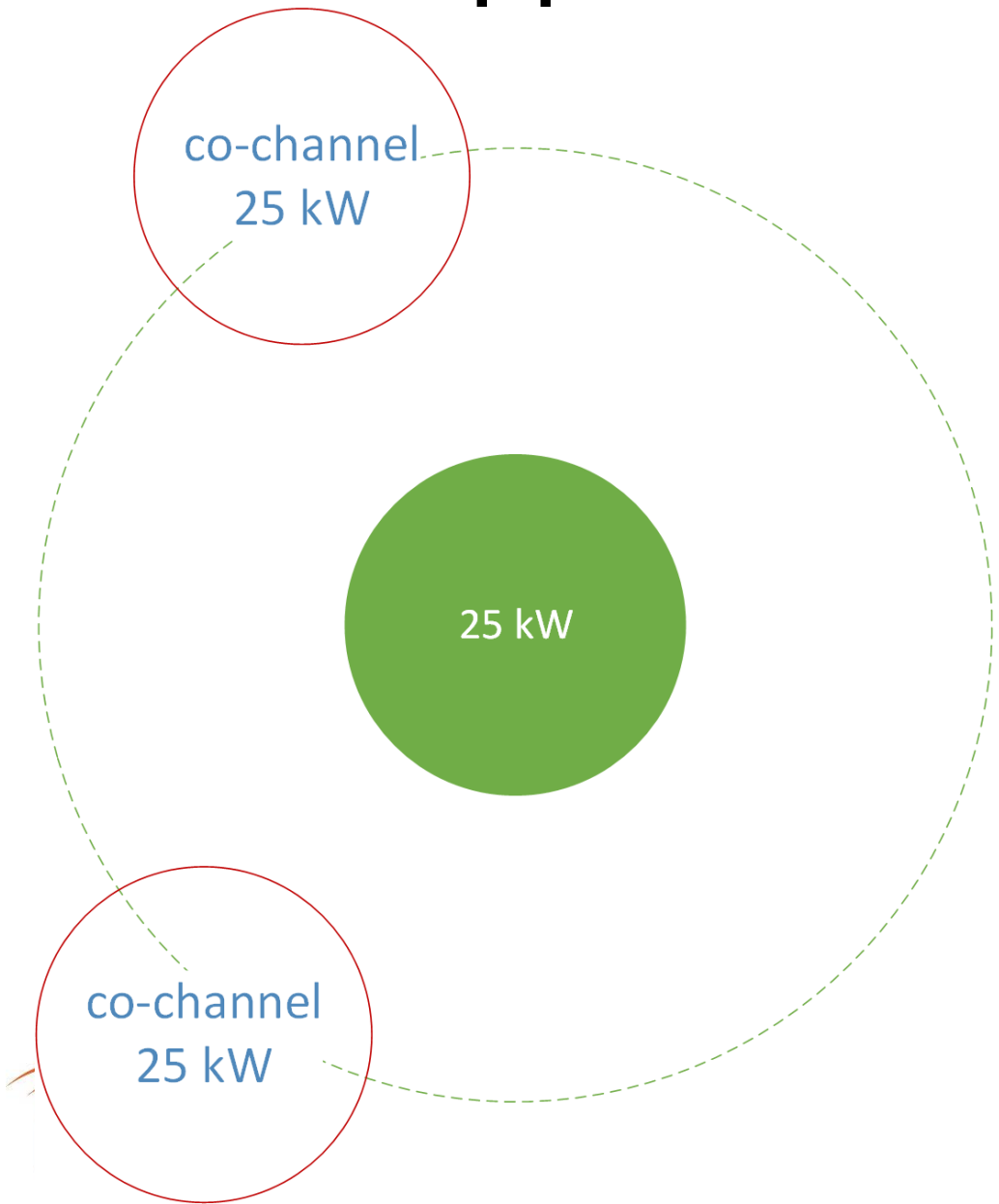
Local content can be on P3 channel (MP3 mode) with common P1 channel

Each node can warn about hazards within the area on P3 channel.

Tunnel micro booster provides continuous underground service.

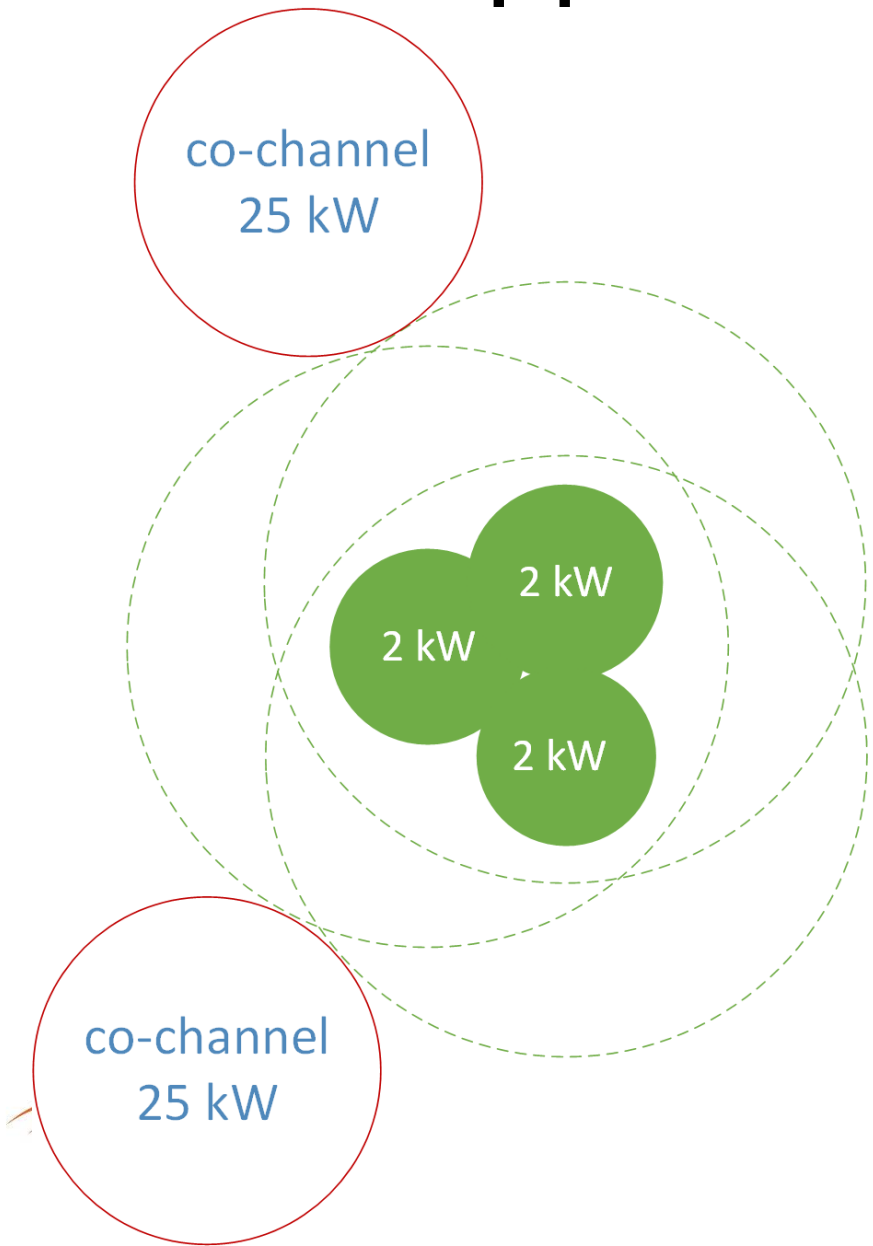
Tunnel specific public safety information can be carried on P3 partitions

# Application: The FM Band is Full



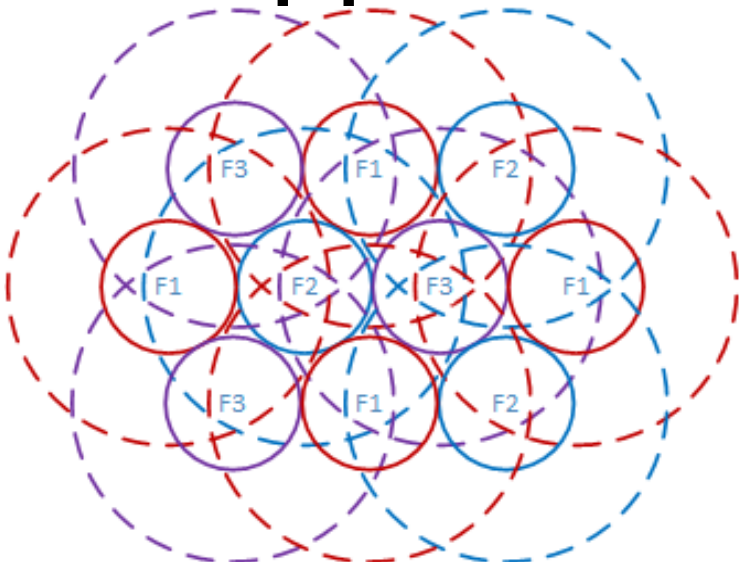

- Difficult to find white space for high power stations due to large F(50,10) interfering contour
- Also consider 1st and 2nd adjacent channel protection
- Directional antenna patterns can only help so much
- Difficult to find translator frequencies

# Application: The FM Band is Full



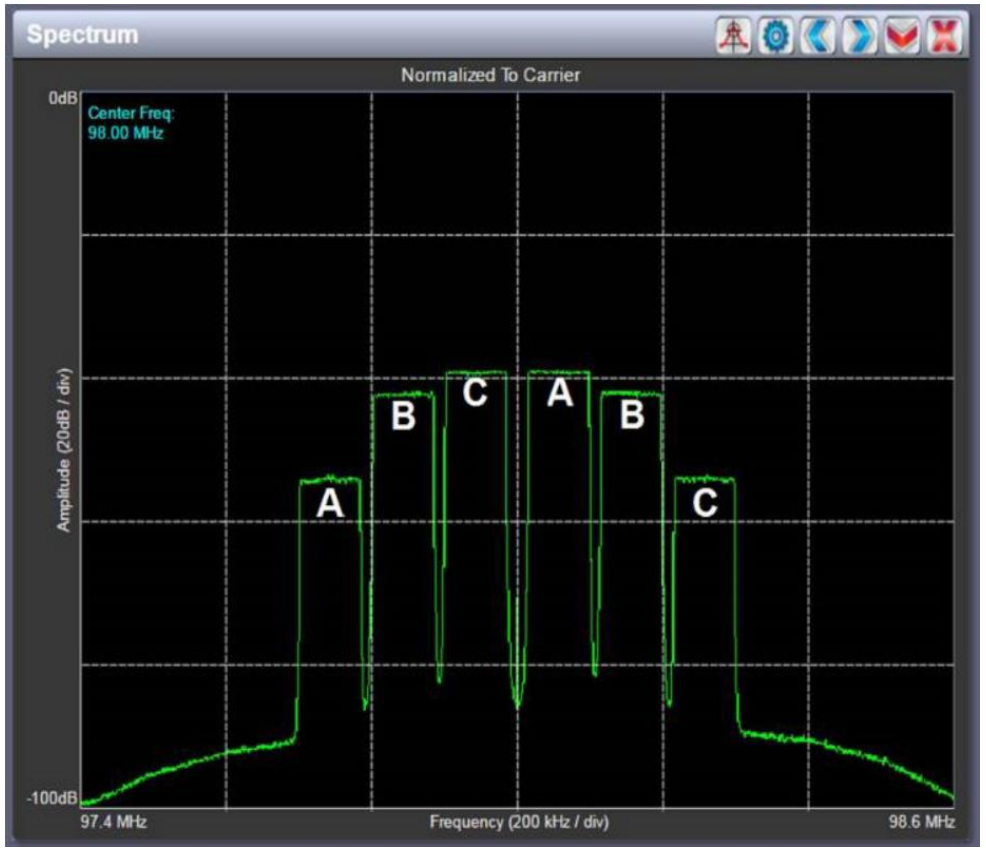

- Lower power transmitters reduce interfering contour
- Transmission power savings
- We can now create new “equivalent” full power stations for the community of license.
  - fringe listening will be reduced
- Future station expansion possibilities
- We must minimize SFN interference through synchronization and planning.

# Application: Wide Area Coverage




- Public broadcasters with a mandate for national, state–wide, or wide area coverage
  - mandated to reach majority of population
- Translator network requires at least 3 channel allocations – more in difficult terrain
- Also consider adjacent channels
- SFN is spectrum efficient

# Application: All Digital IBOC

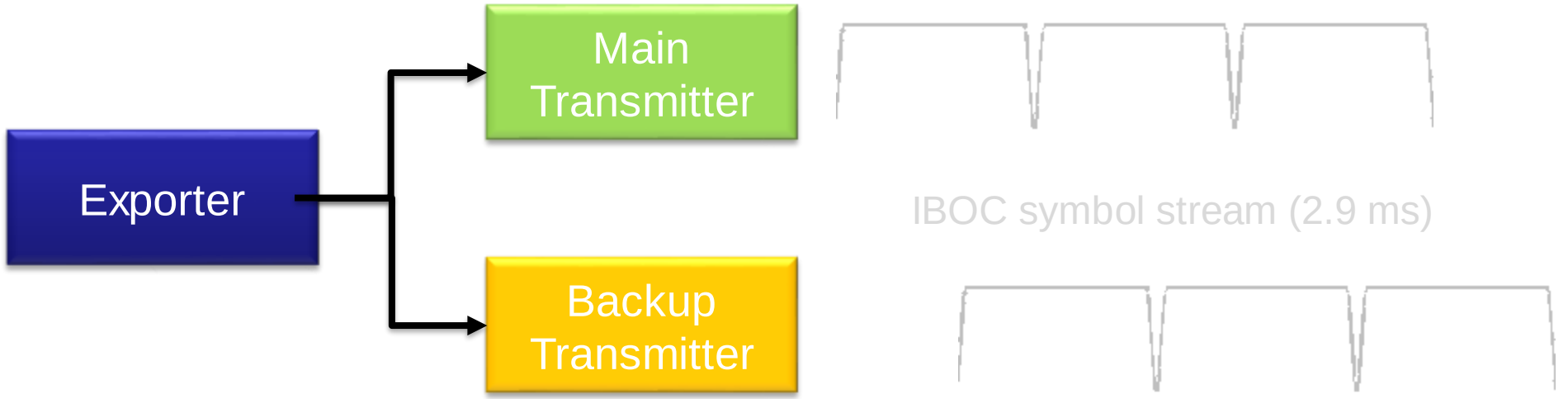



- Hybrid HD radio will remain limited by the FM carrier
- All Digital IBOC is ideally suited for SFN operation
  - Stations A,B, or C are optional in SFN
- Offers more diverse content using the existing spectrum and existing receivers.
- HD Multiplex combines multiple IBOC signals without the FM carrier
  - 380 kbps, 9-15 audio services

# Application: Backup Transmitter/Exciter

Today exgine modulators are not time synchronized.

Variances typically vary from 100μs to 10ms.

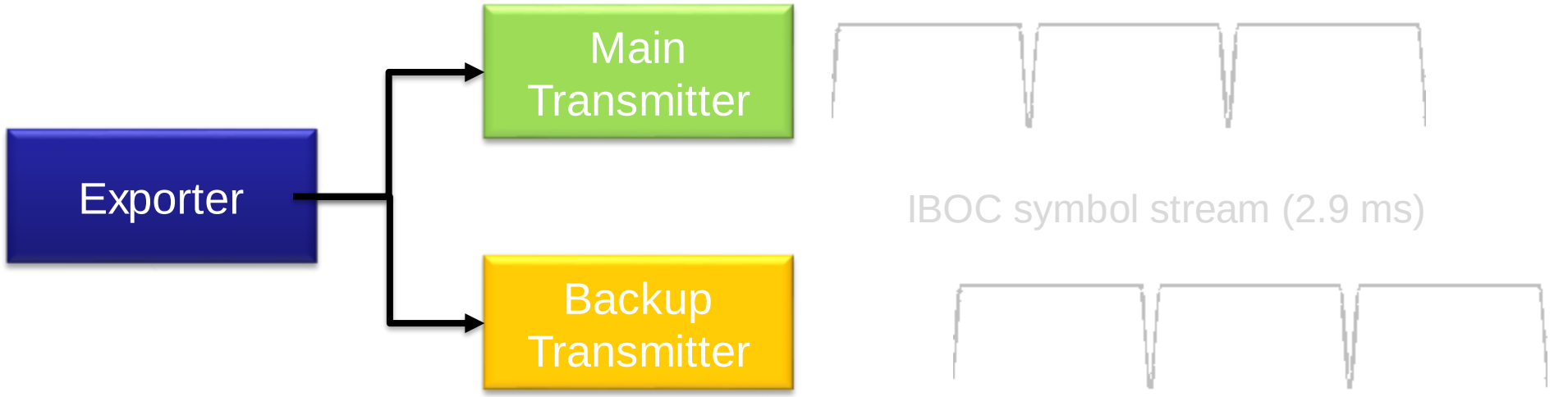


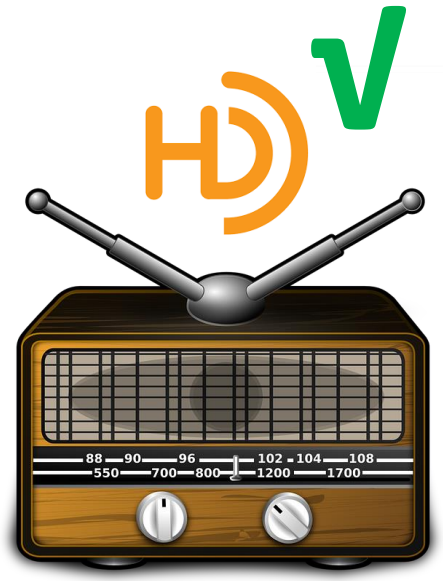

Receiver becomes confused having locked to the first IBOC symbol. Some receivers may lose HD lock for minutes until tuned off channel. Diversity delay has changed.

# Application: Backup Transmitter/Exciter

IBOC modulation must be identical.

IBOC symbols must be aligned across main and backup.




Receiver maintains HD lock. Diversity delay is maintained.

# Establishing SFN Parameters

1. What are the required Desired vs Undesired (D/U) ratios?
2. What are the required timing parameters?

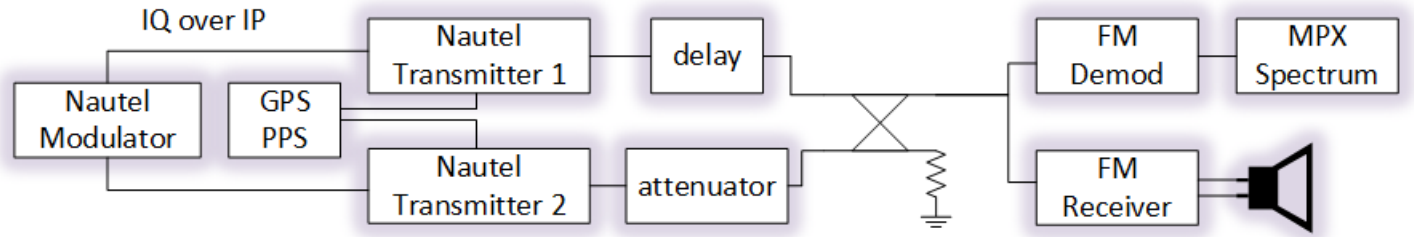
# FM SFN Protection Ratios

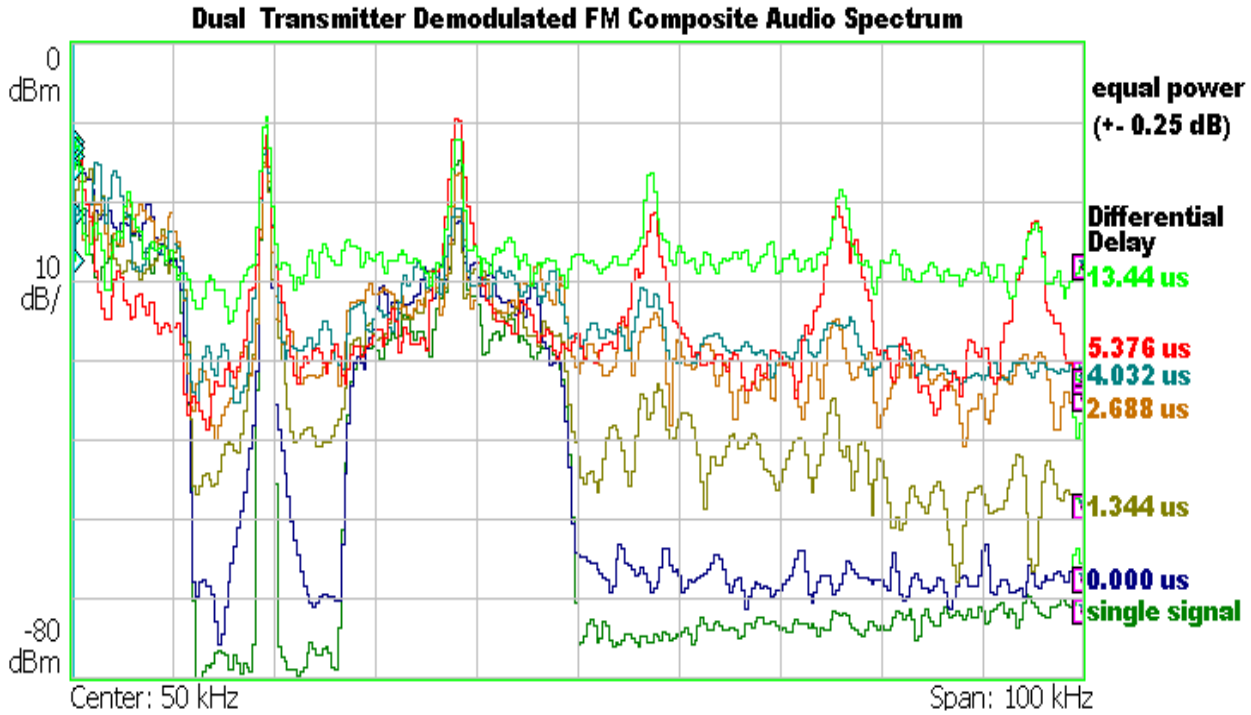
| Time Delay | Mono FM | | Stereo FM | |
|---|---|---|---|---|
| Impairment Grade | 3 | 4 | 3 | 4 |
| 2 µs | <1 dB | 1 dB | 4 dB | 6 dB |
| 5 µs | 1 dB | 2 dB | 10 dB | 12 dB |
| 10 µs | 1 dB | 3 dB | 14 dB | 16 dB |
| 20 µs | - | 11 dB | - | - |
| 40 µs | - | 20 dB | - | - |

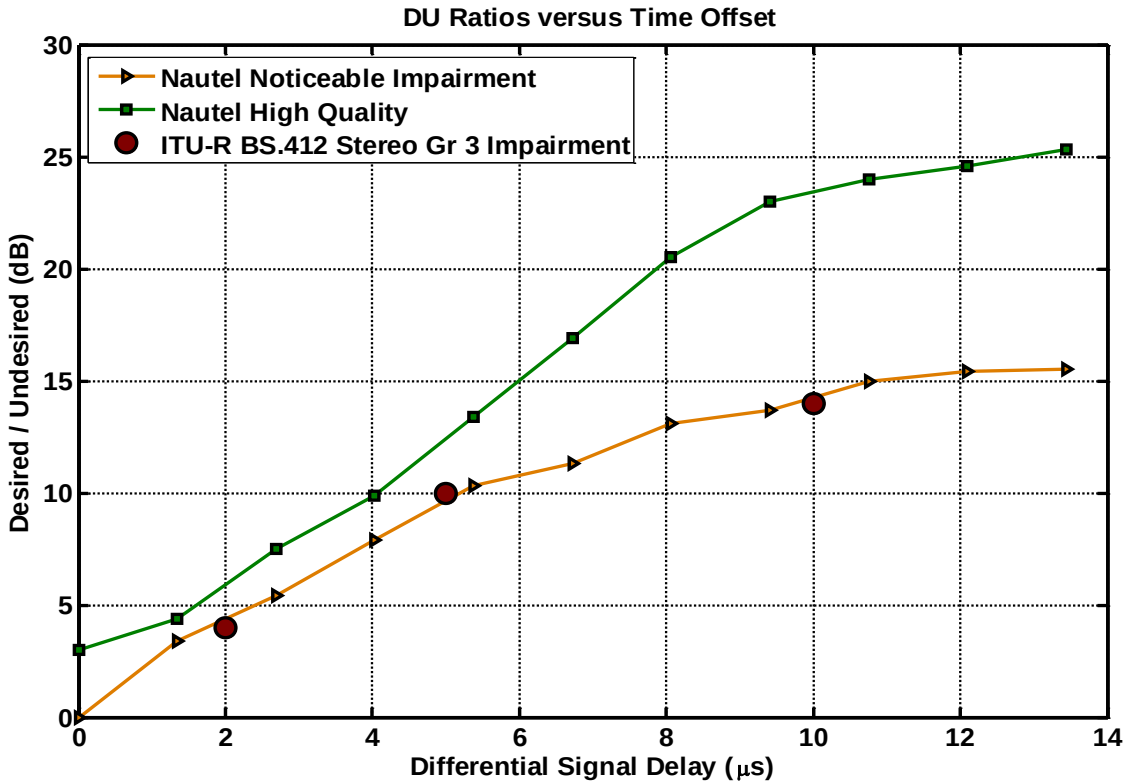
Results from ITU-R BS.412

- ITU Impairment Grades
  - 5: Excellent quality — imperceptible impairment
  - 4: Good quality — perceptible impairment, but not annoying
  - 3: Fair quality — slightly annoying impairment
- e.g. a stereo FM signal 14 dB stronger to a 10 µs delayed interferer produces grade 3 impairment.
- 10 µs represents 3 km signal flight time

# Nautel FM Stereo SFN Lab Tests

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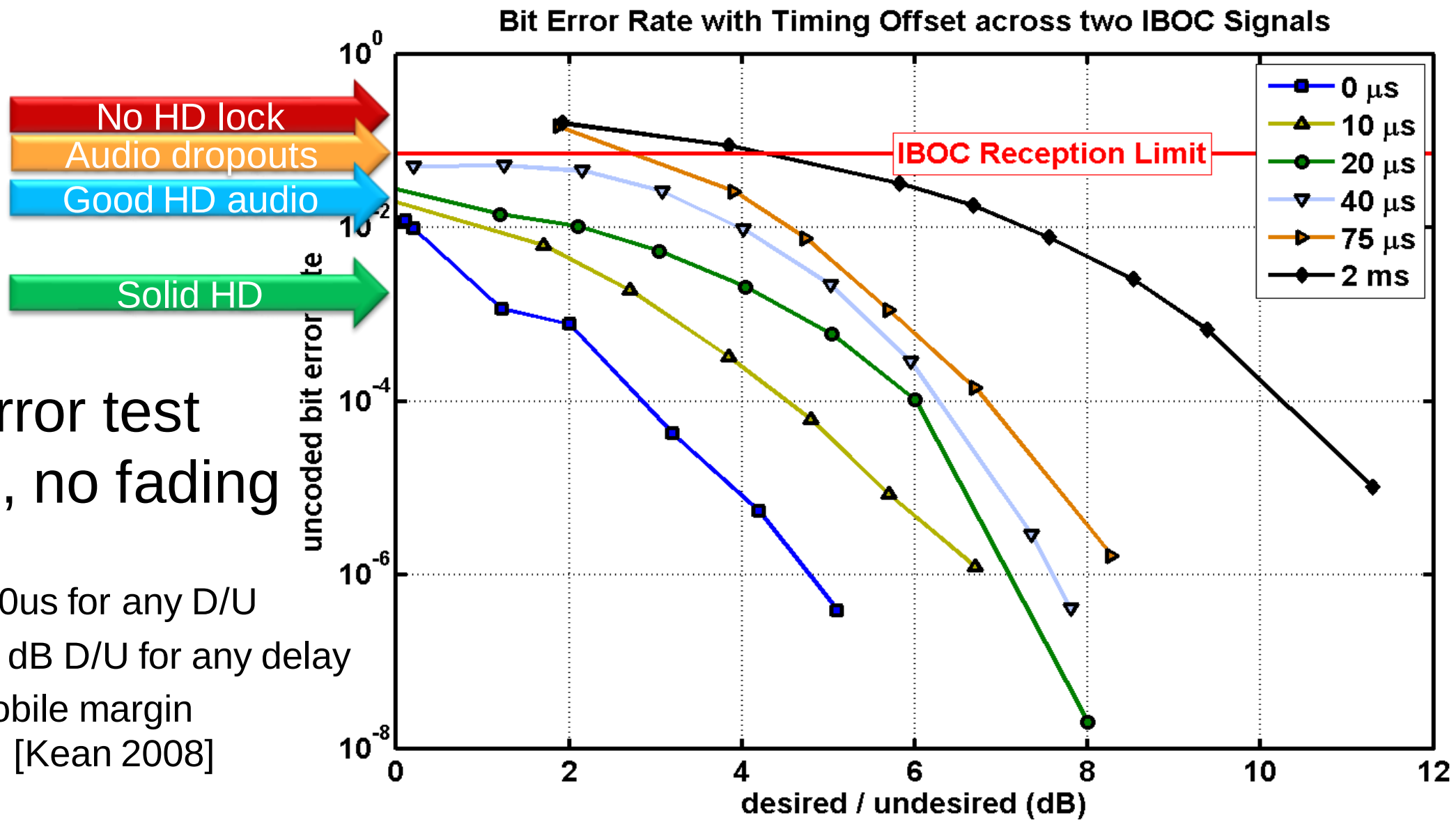
# Nautel IBOC SFN Lab Tests




## Raw bit error test prior FEC, no fading

- MP1 mode
- HD lock at 40us for any D/U
- HD lock at 4 dB D/U for any delay
- Add 3 dB mobile margin

[Kean 2008]

# Solving for Constant Delay Lines

$d1 = vct$ $\quad d1^2 = (c + x)^2 + y^2$

$d2 = vc(t - \Delta t)$ $\quad d2^2 = (c - x)^2 + y^2$

$v_c$ speed of light

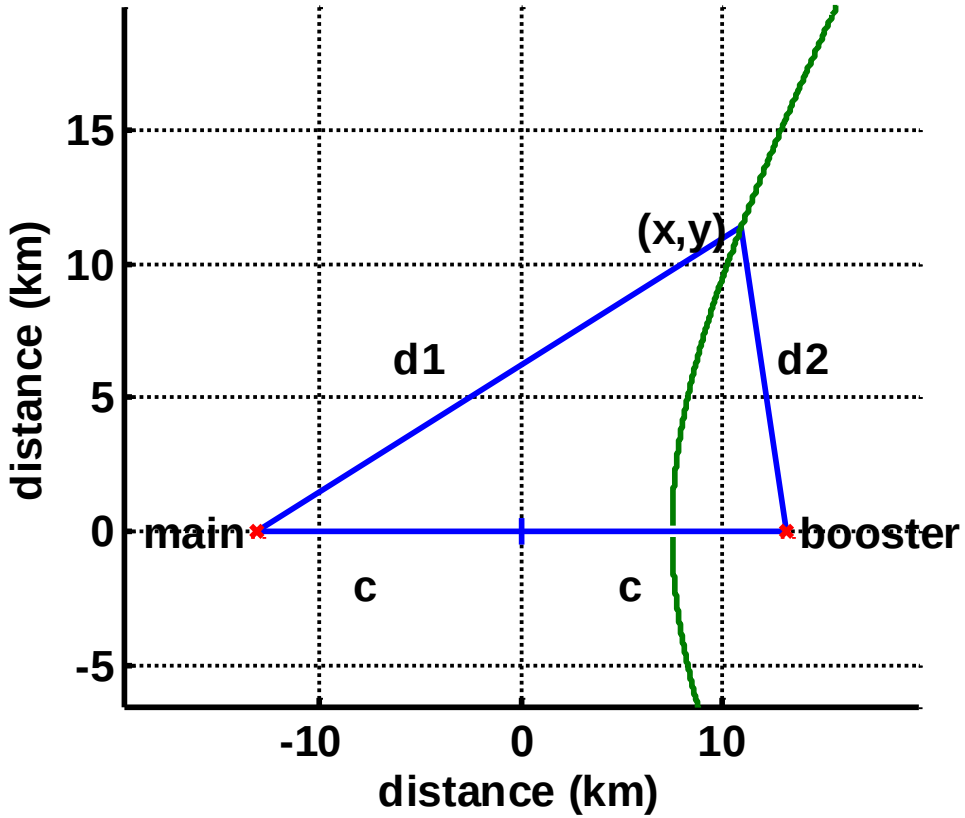
$\Delta t$ configurable booster time offset

Solve for x and y:

$x(t) = \frac{d1^2 - d2^2}{4c}$ $\quad y(t) = \pm\sqrt{d1^2 - (x + c)^2}$

$\forall\ t > \frac{2c}{v_c} - \Delta t$

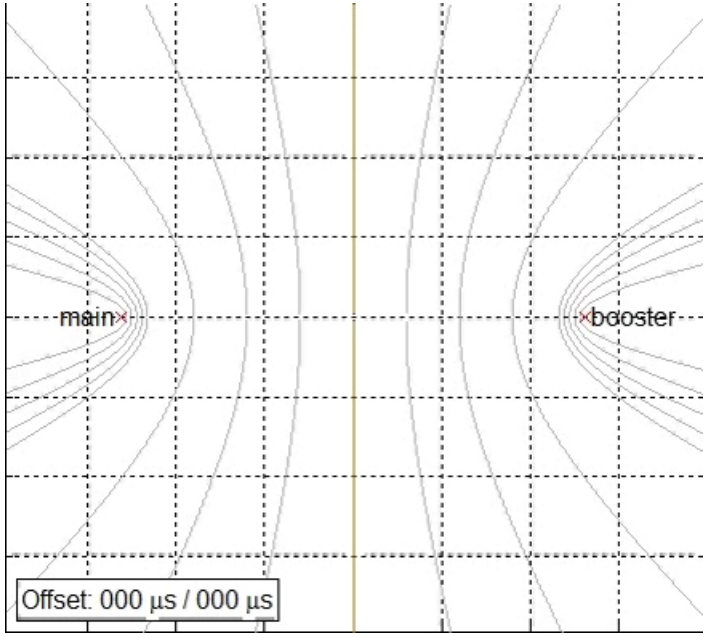
**50us booster delay:**



# Time Sync: Synchronized Transmission

**Step 1**

Achieve modulation and time synchronization

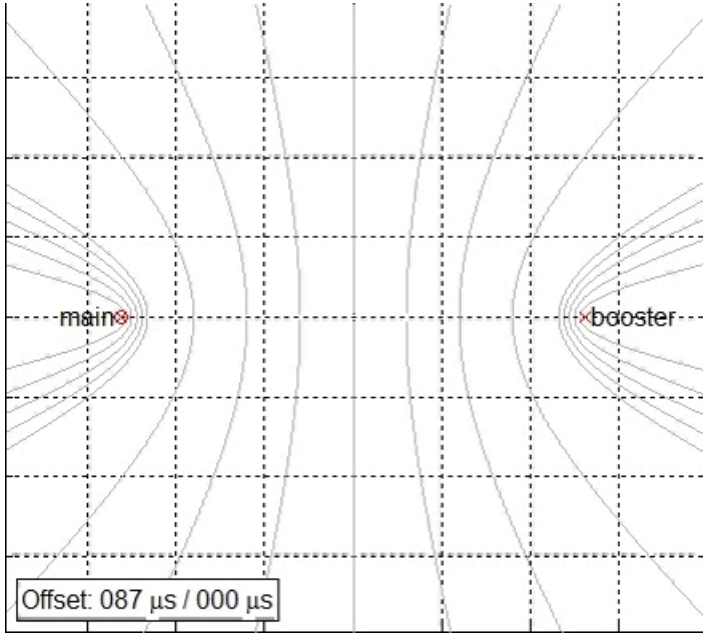


# Time Sync: Zeroed Delay

**Step 2**

Calibrate out delay primary to booster delay

26.2 km or 87.3µs

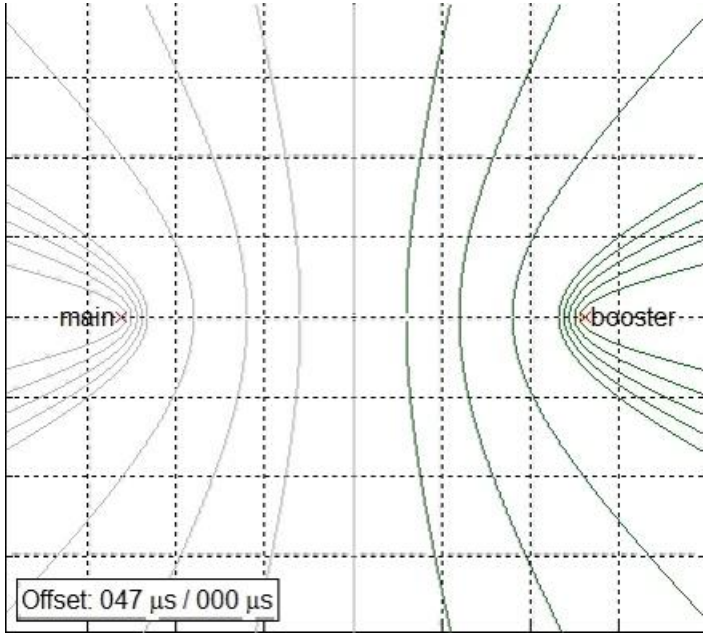


# Time Sync: Advance Transmission

**Step 3**

Advance transmission
by desired offset (40µs)

87.3µs - 40µs = 47.3µs



# Matching D/U Signal Ratios to Signal Delay

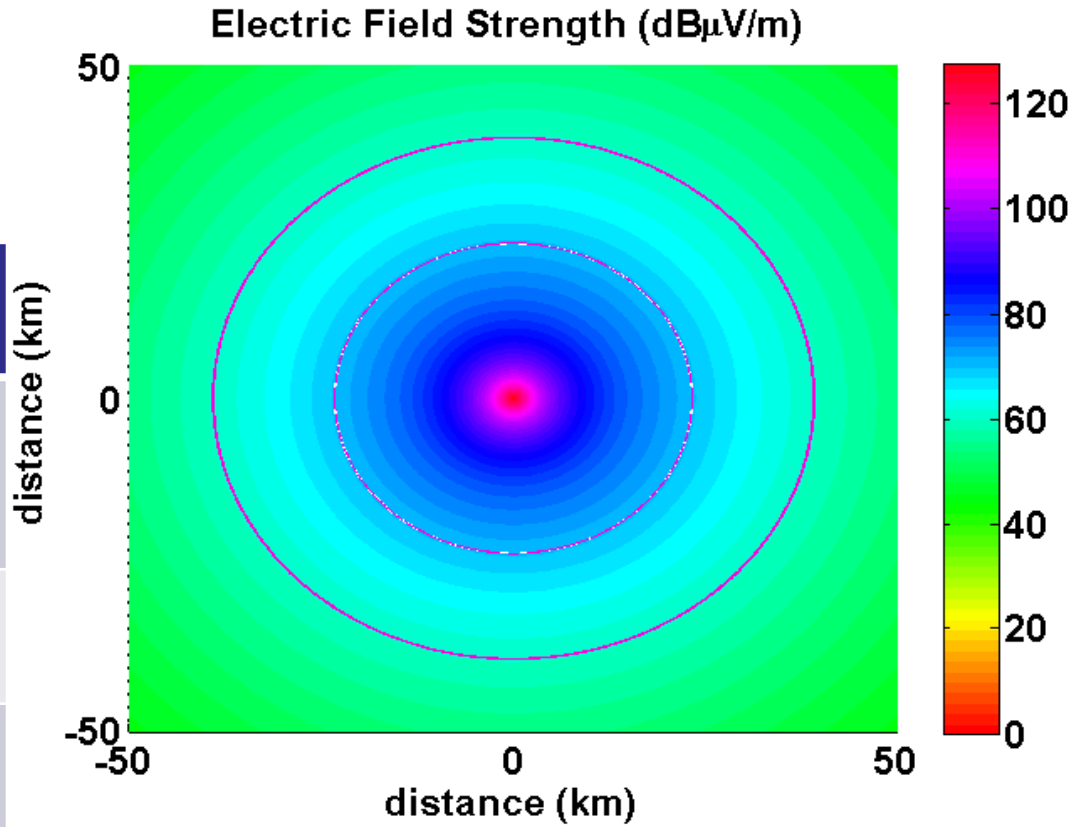
# Simulation: Matching D/U to Delay

FCC F(50,50) curves for 25 kW, 100 m

- Omnidirectional antenna pattern
- Shown with **60 dBu and 70 dBu contour**

Worst case flat world – no terrain shielding

| Mode | Desired / Undesired | Time Margin | Condition |
|---|---|---|---|
| FM Stereo | 14 dB | 10 µs | ITU-R BS.412-9 Grade 3 audio impairment<br>Nautel FM impairment tests |
| FM Mono | 3 dB | 10 µs | ITU-R BS.412-9 Grade 4 audio impairment |
| IBOC | 7 dB | 40 µs | Potential loss of HD lock, Nautel IBOC bit error tests with 3 dB added fading margin (MP1/MP3) |



# Stereo FM Synchronization

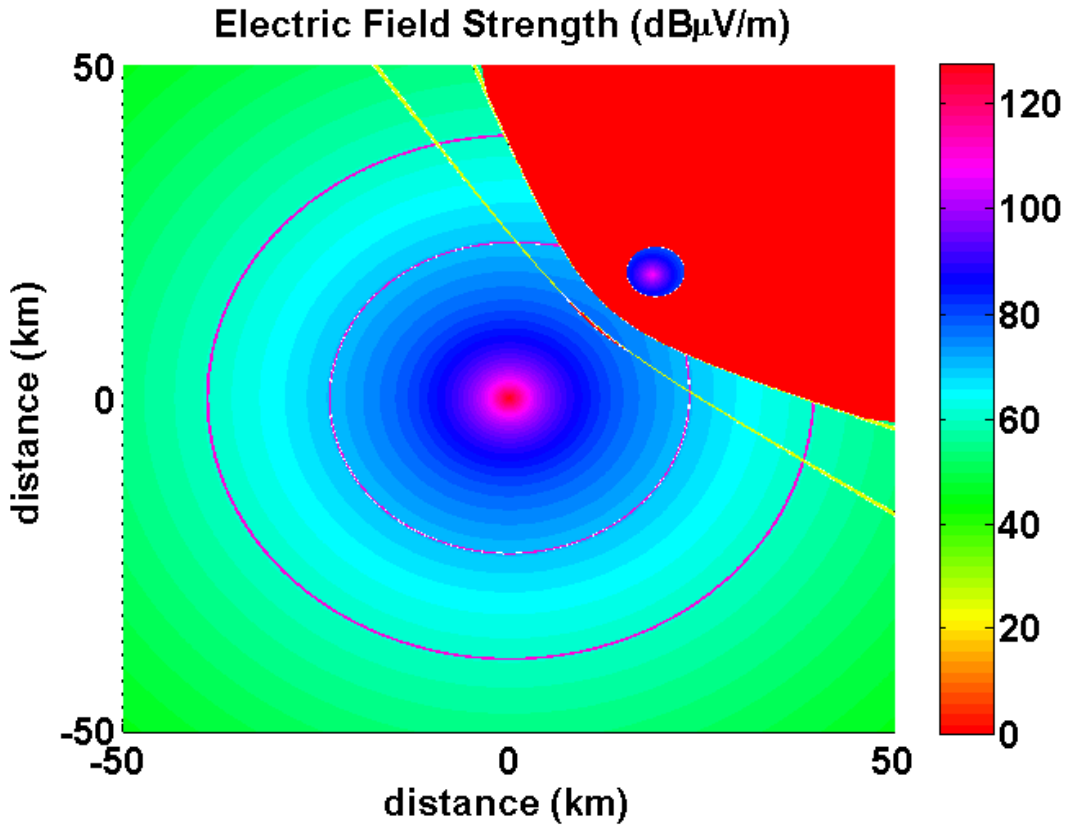
25 kW Class C3 and 250W Booster
- Shown with **60 dBu and 70 dBu contour**

26.2 km or 87.3 µs separation

Large **interference** potential (**14 dB D/U**)
- Booster not reaching city grade contour
- **Terrain shielding is a must !!!**

60 µs booster time advance
- Booster delay 87.3 µs – 60 µs = 27.3 µs
- Meets primary wave 30 µs or 9 km out

**10 µs timing margin** provides small buffer
- 14 dB D/U change over 3 km is not possible
- No seamless coverage



# Mono FM Synchronization

Smaller **interference** potential (**3 dB D/U**)

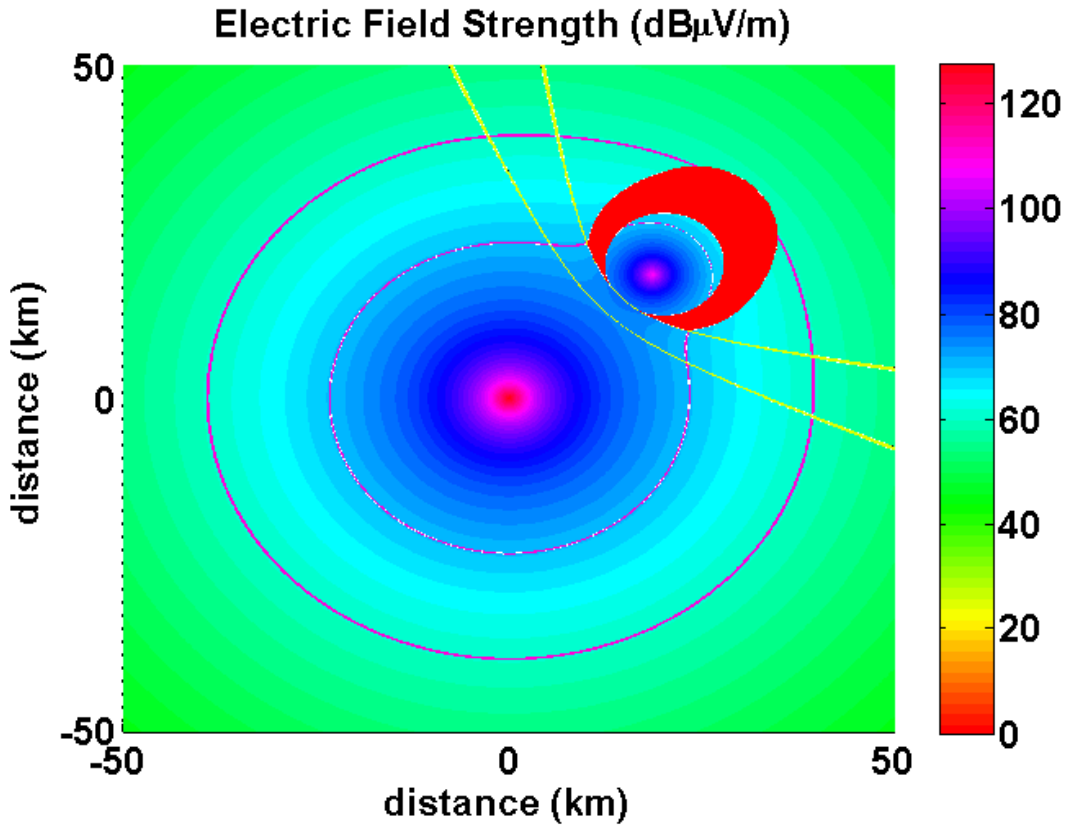
- Booster exceeds **city grade contour**

45 µs booster time advance

- Booster delay 87.3 µs – 45 µs = 42.3 µs
- Meets primary wave 22.5 µs or 6.7 km out

**10 µs timing margin** provides small buffer

- 3 dB D/U change over 3 km can be possible
- Limited seamless coverage is possible
- Time advance could be decreased to curve the timing margin for a better match



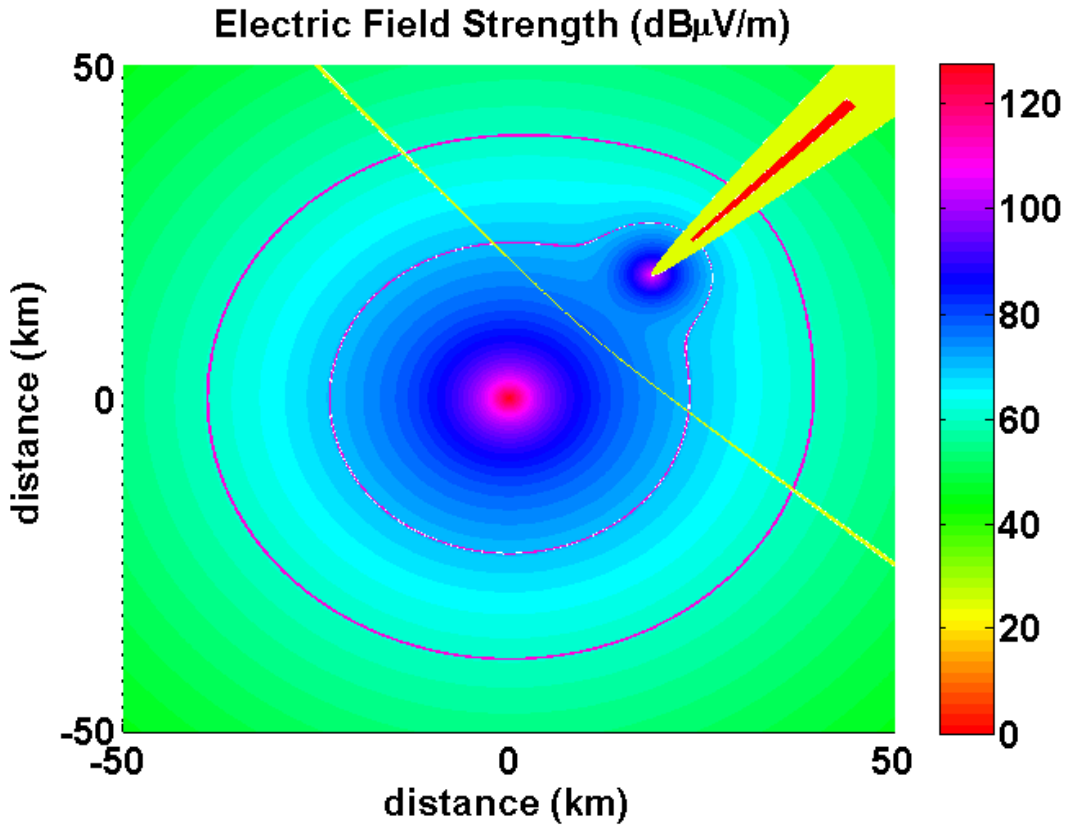
# IBOC Synchronization

Hybrid FM+IBOC System
- Primary 2.5 kW IBOC at -10 dBc injection
- Booster 25 W IBOC at -10 dBc injection

Minimal **interference** potential (7 dB D/U)
- Booster increases **city grade contour**
- Little impact on combined **60 dBu contour**

40 µs booster time advance
- Booster delay 87.3 µs – 40 µs = 47.3 µs
- Meets primary wave 20 µs or 6 km out

**40 µs timing margin** provides large buffer
- Seamless coverage is possible



# Expanding Your IBOC Coverage

Hybrid FM+IBOC System

- Primary 2.5 kW IBOC at -10 dBc injection
- 3 Boosters at 25 W IBOC at -10 dBc injection

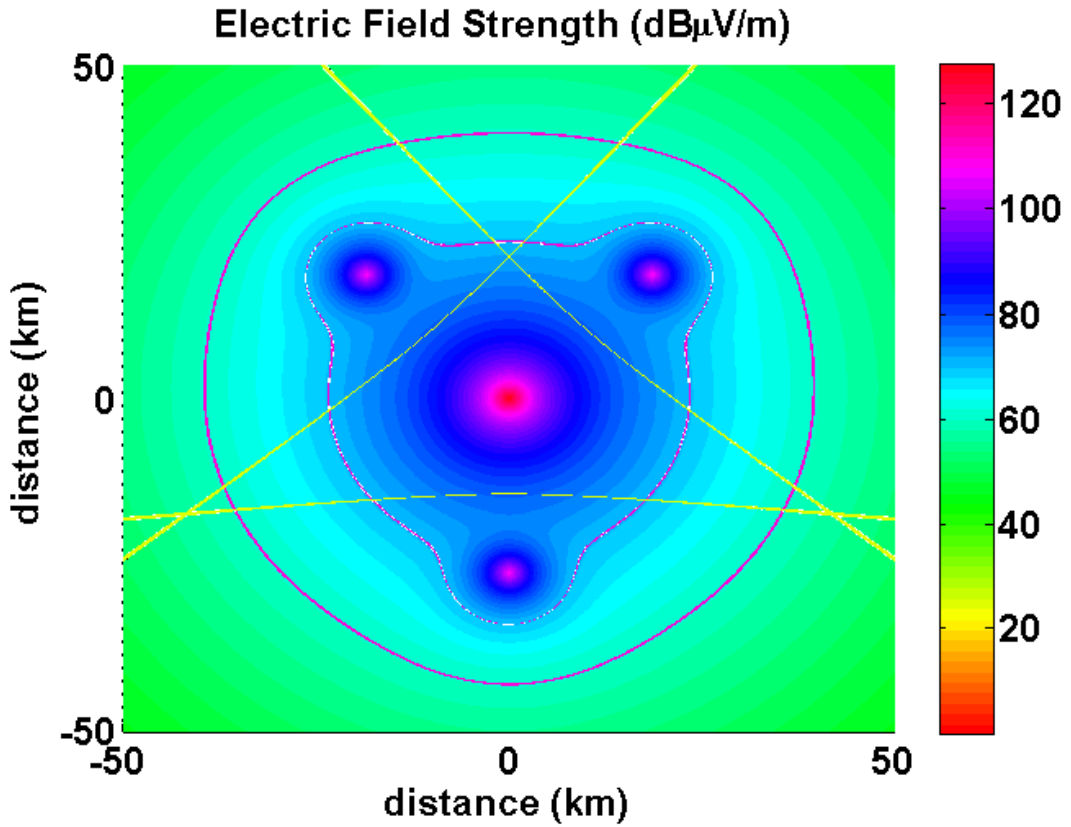
No IBOC **interference** expected

- Big increase in **city grade contour**
- Some increase in combined **60 dBu contour**

39 µs booster time advance

- Booster to booster interference not shown
- Extended seamless coverage beyond station protected contour
- Perhaps reduce primary IBOC injection and save transmission power

**In theory this is legal today !!!**

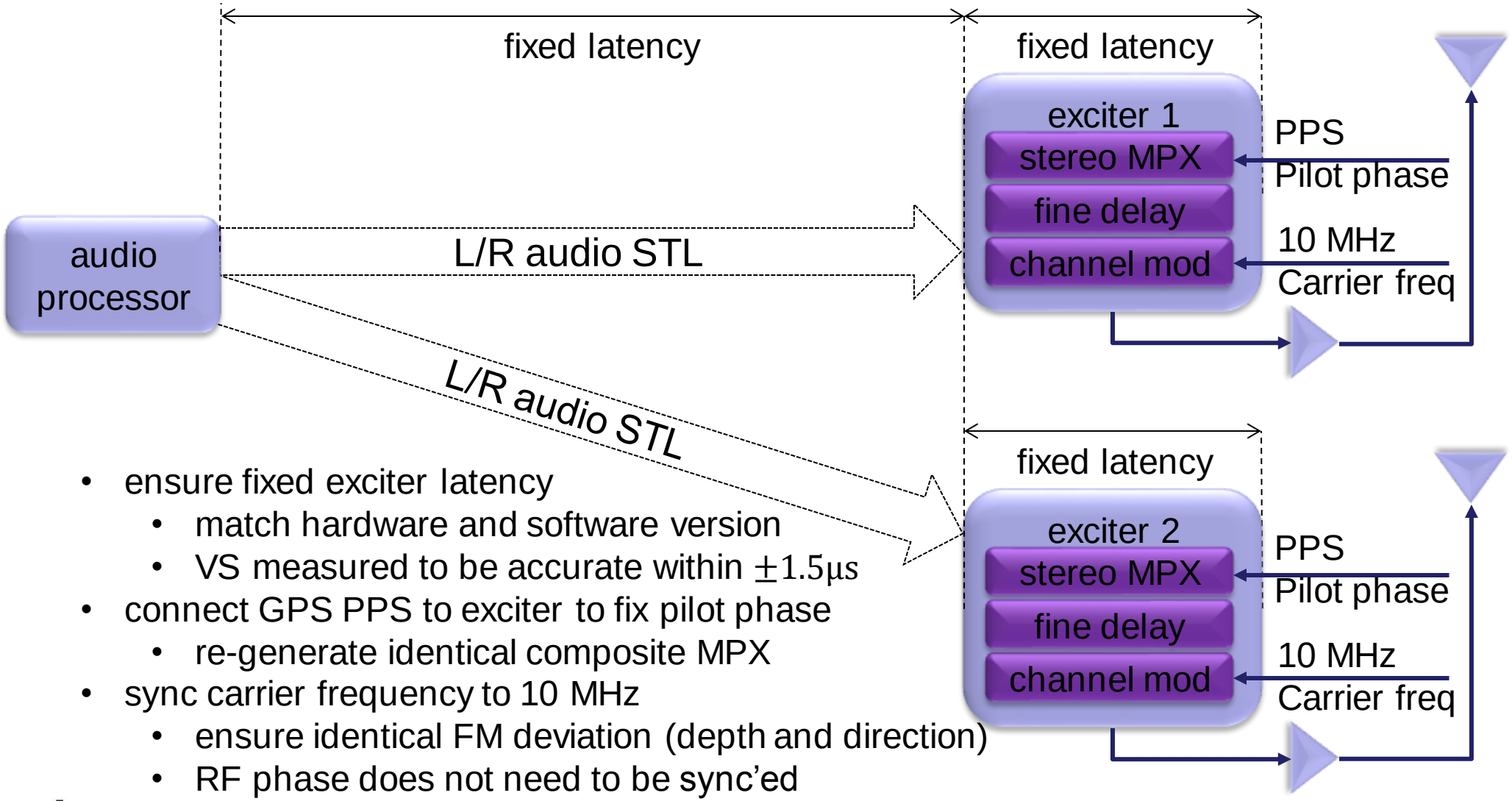


# SFN Implementation

# Step 1: RF Consultant

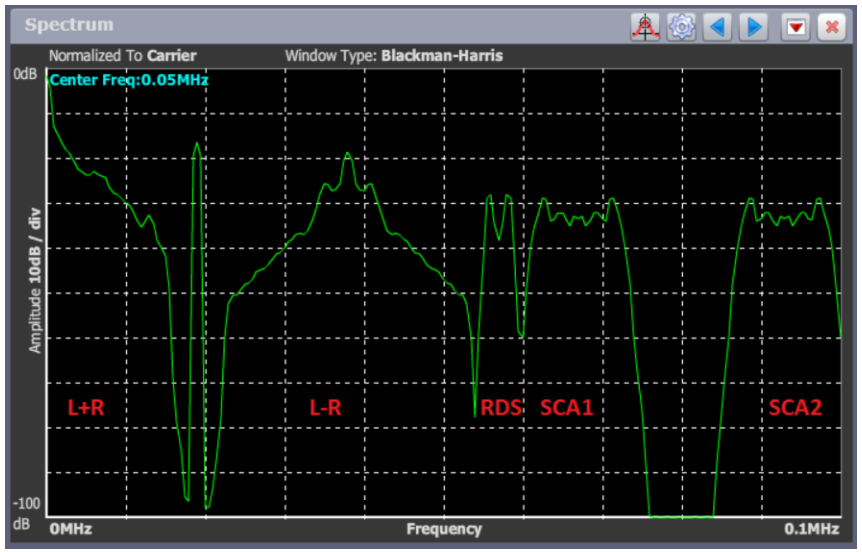
- A competent broadcast engineer with expertise in SFN installations is a must:
  - perform RF coverage simulations
  - evaluate booster locations and antenna patterns
  - identify interference zones and terrain shielding
  - determine optimal time offsets; may be different for FM and IBOC
  - handle legal matters
- Nautel provides components, system design is the responsibility of a professional consultant.

# Step 2: Synchronize the FM Audio Signal




- ensure fixed exciter latency
  - match hardware and software version
  - VS measured to be accurate within ±1.5µs
- connect GPS PPS to exciter to fix pilot phase
  - re-generate identical composite MPX
- sync carrier frequency to 10 MHz
  - ensure identical FM deviation (depth and direction)
  - RF phase does not need to be sync'ed
- **no solution for RDS or SCA synchronization**

# Step 2: Synchronize the FM MPX Signal




fixed latency

GPS or PTP sync

audio processor

MPX encoder

stereo MPX

Variable STL delay

MPX decoder

fixed latency

exciter 1

fine delay

channel mod

10 MHz Carrier freq

Variable STL delay

GPS or PTP sync

MPX decoder

fixed latency

exciter 2

fine delay

channel mod

10 MHz Carrier freq

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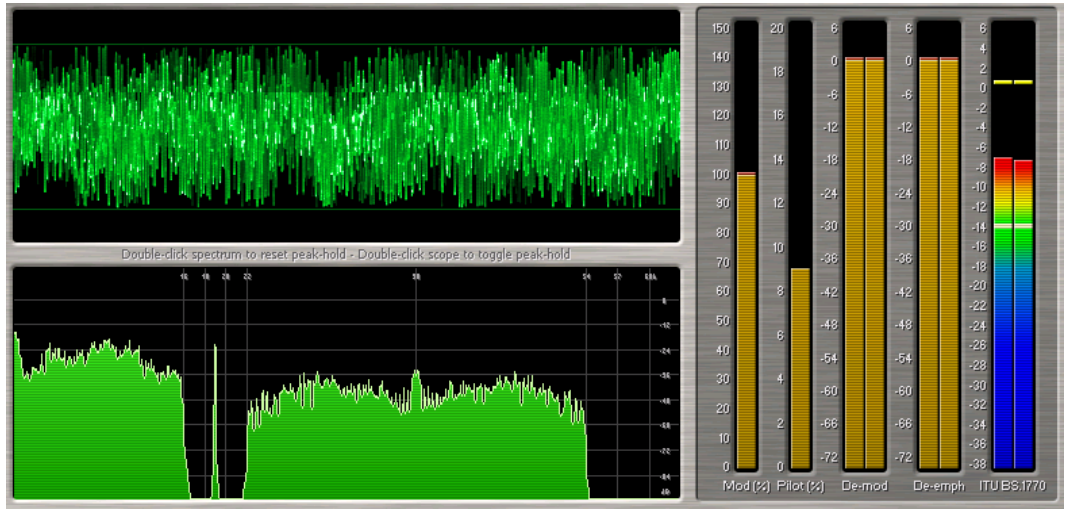
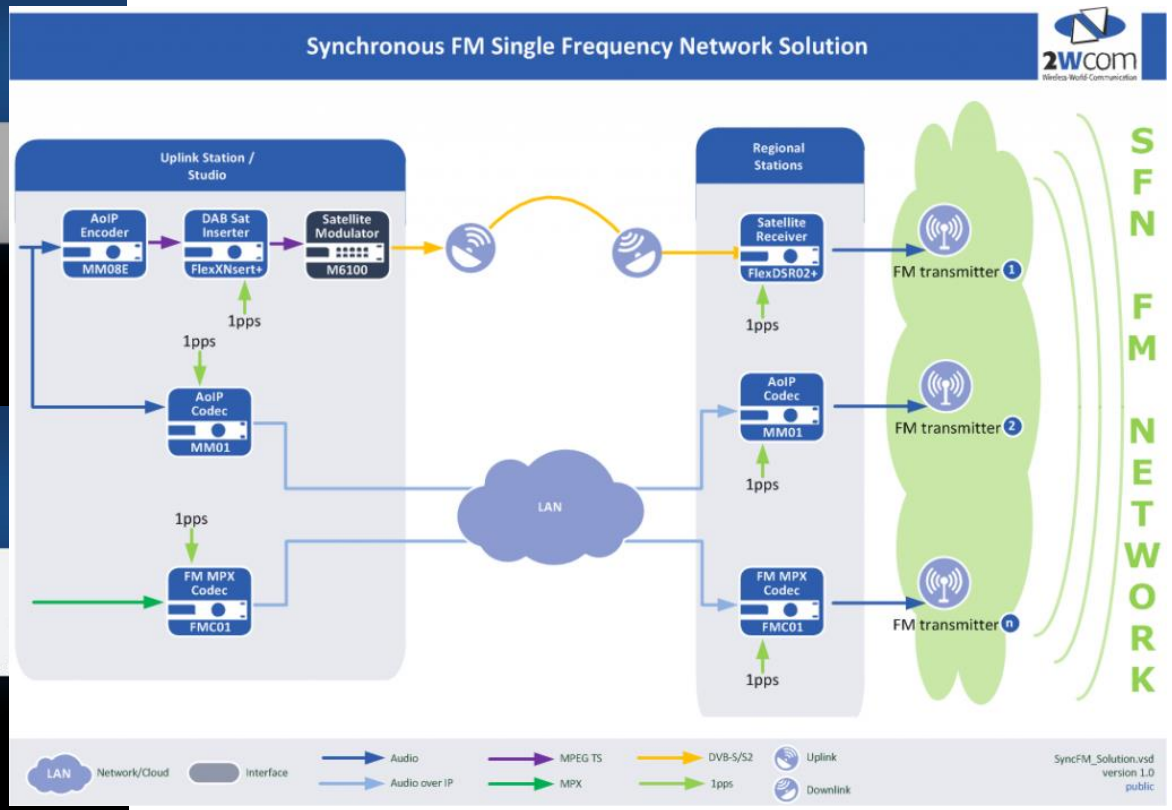
# MPX Sync: Sigmacom EtherMPX

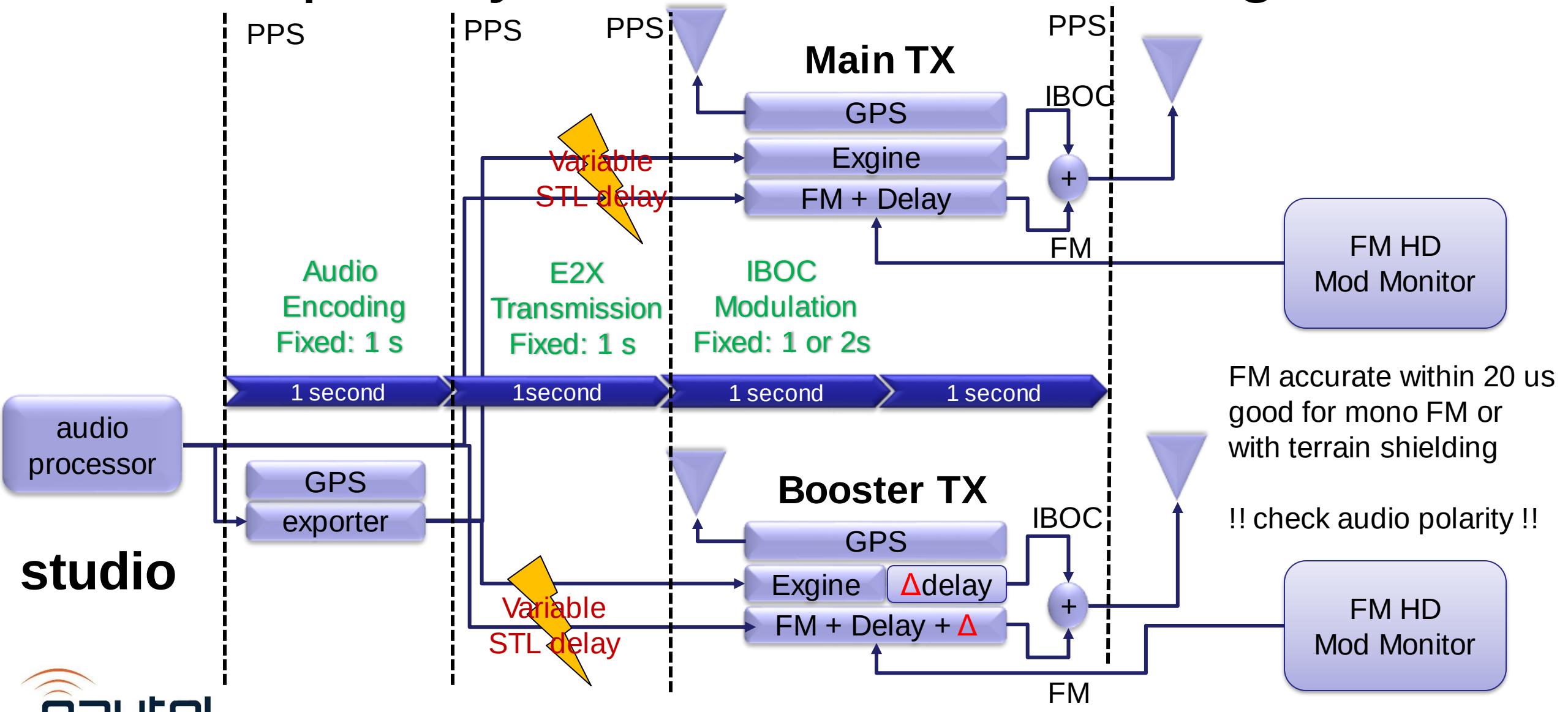




SFN Ready

# MPX Sync: 2wcom FMC01

# Step 3: Synchronize the IBOC Signal

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# What equipment do you need?

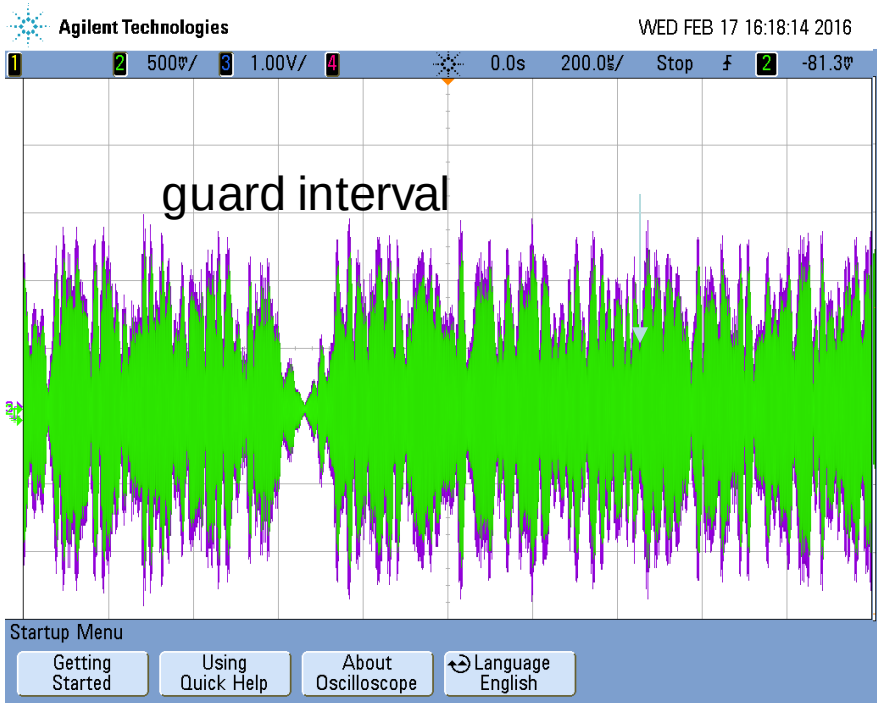
For FM analog only:

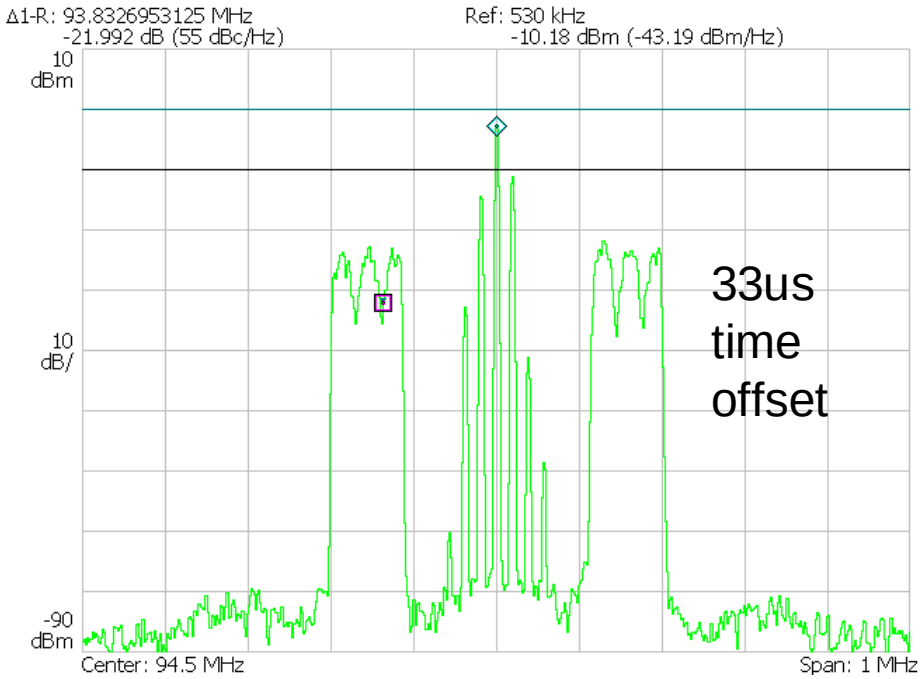
- Main transmitter – dependent on power level
- Booster transmitter(s) – dependant on power level
- MPX over AES codecs with time sync: $3-4,000 / site

Adding HD Radio:

- Nautel transmitter for both main and booster
- Importer+
- Exporter+
- FM + HD Modulation monitor for each site

# Lab Results: Digital Startup




**Startup Delay: better than ± 2µs (0 samples)**

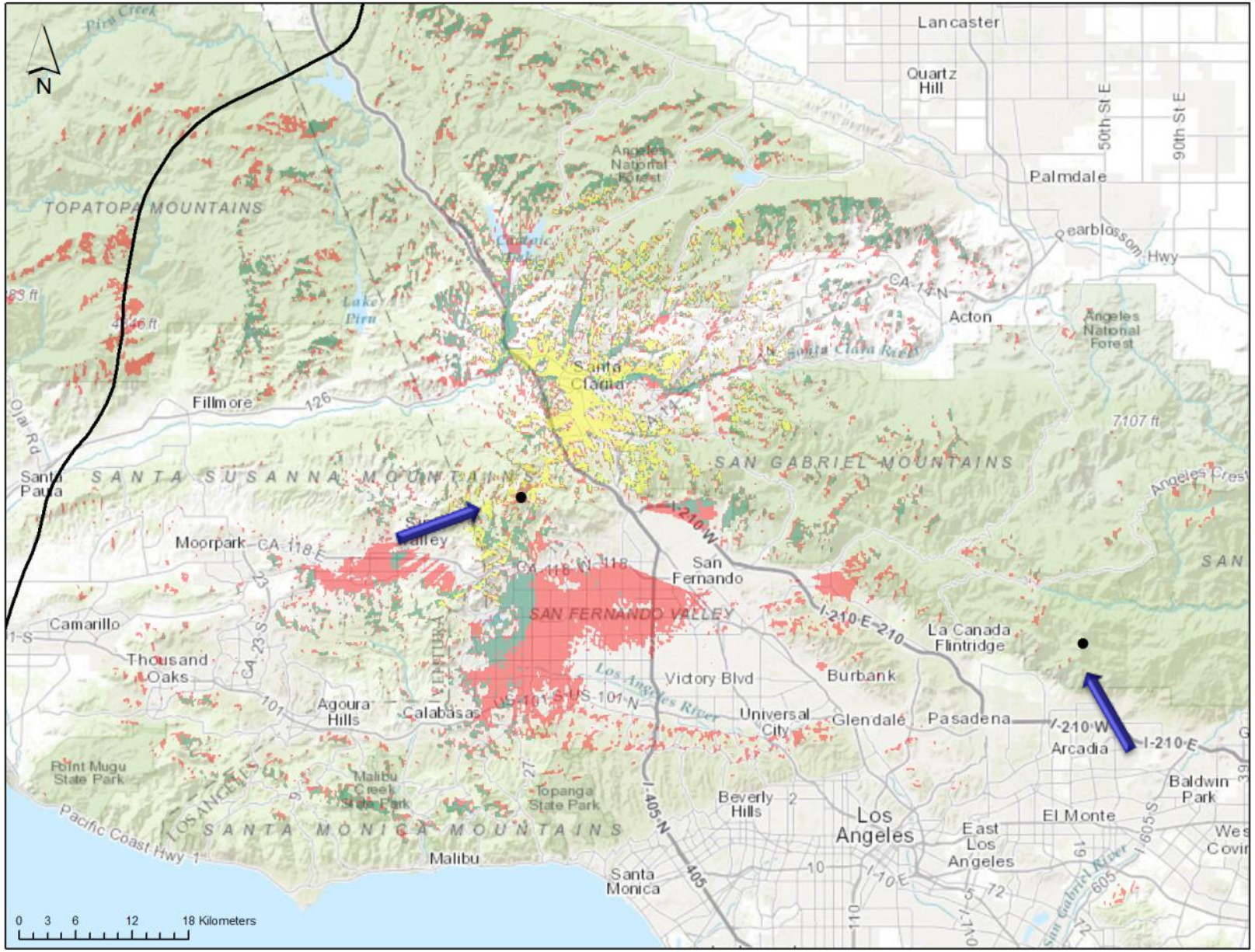
**Improved Digital Diversity Delay Stability**

(unsync'ed typical ±400 µs to 3 ms)

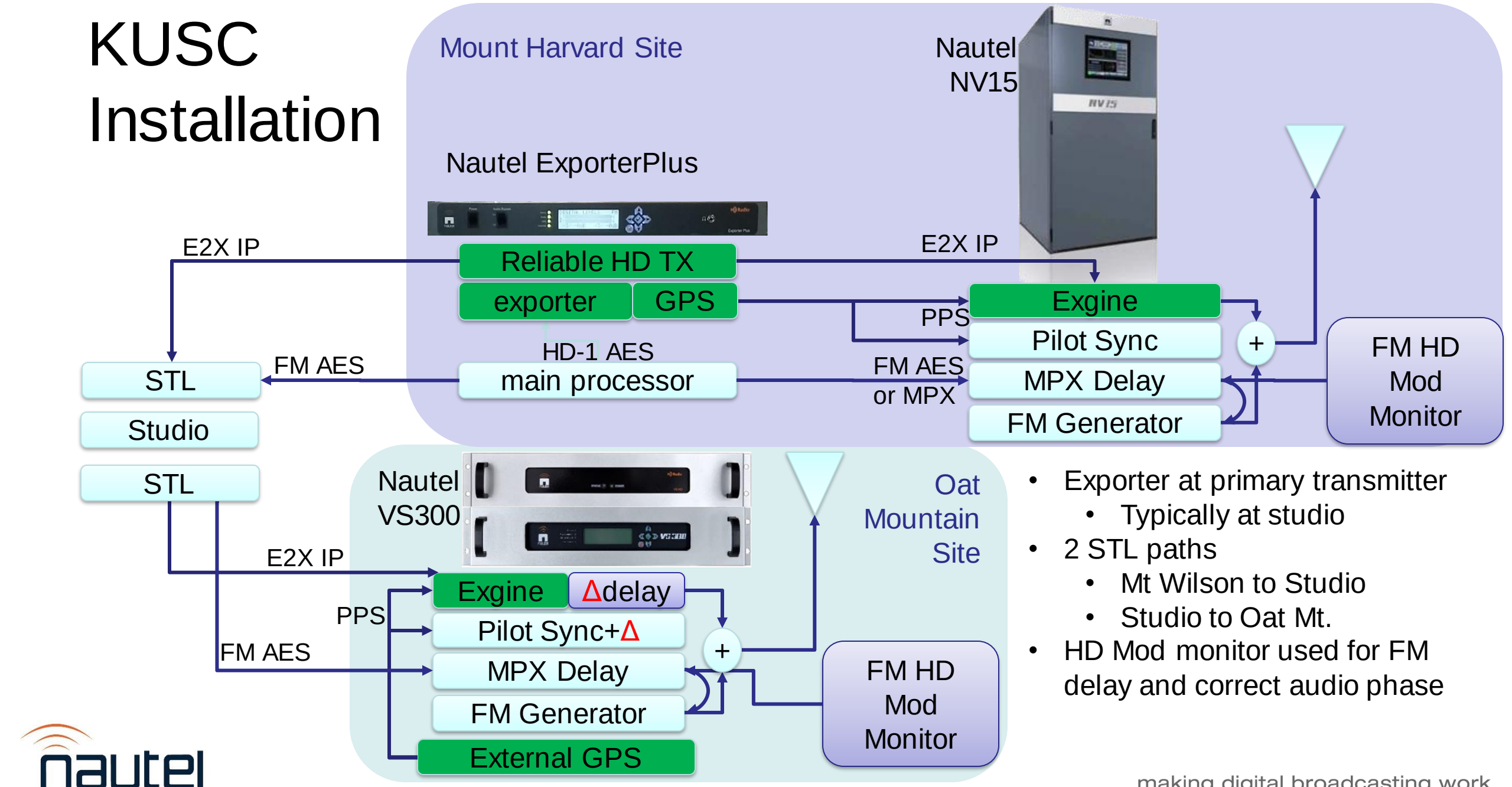
# Field Trial: KUSC, Los Angeles

# Signal coverage Comparison: KUSC-FM

- Main transmitter, 39 kw DA on Mt. Harvard (no booster)
  - Yellow: portable
  - Green: in-home
  - Red: in-car
- Signal coverage from booster, 200w DA on Oak Mountain, Porter Ranch, toward Santa Clarita
  - Same color coding
  - High signal levels in Santa Clarita
  - Terrain causes signal fragmentation
  - Side and back radiation on antenna causes signal in San Fernando Valley



# KUSC Installation




- Exporter at primary transmitter
  - Typically at studio
- 2 STL paths
  - Mt Wilson to Studio
  - Studio to Oat Mt.
- HD Mod monitor used for FM delay and correct audio phase

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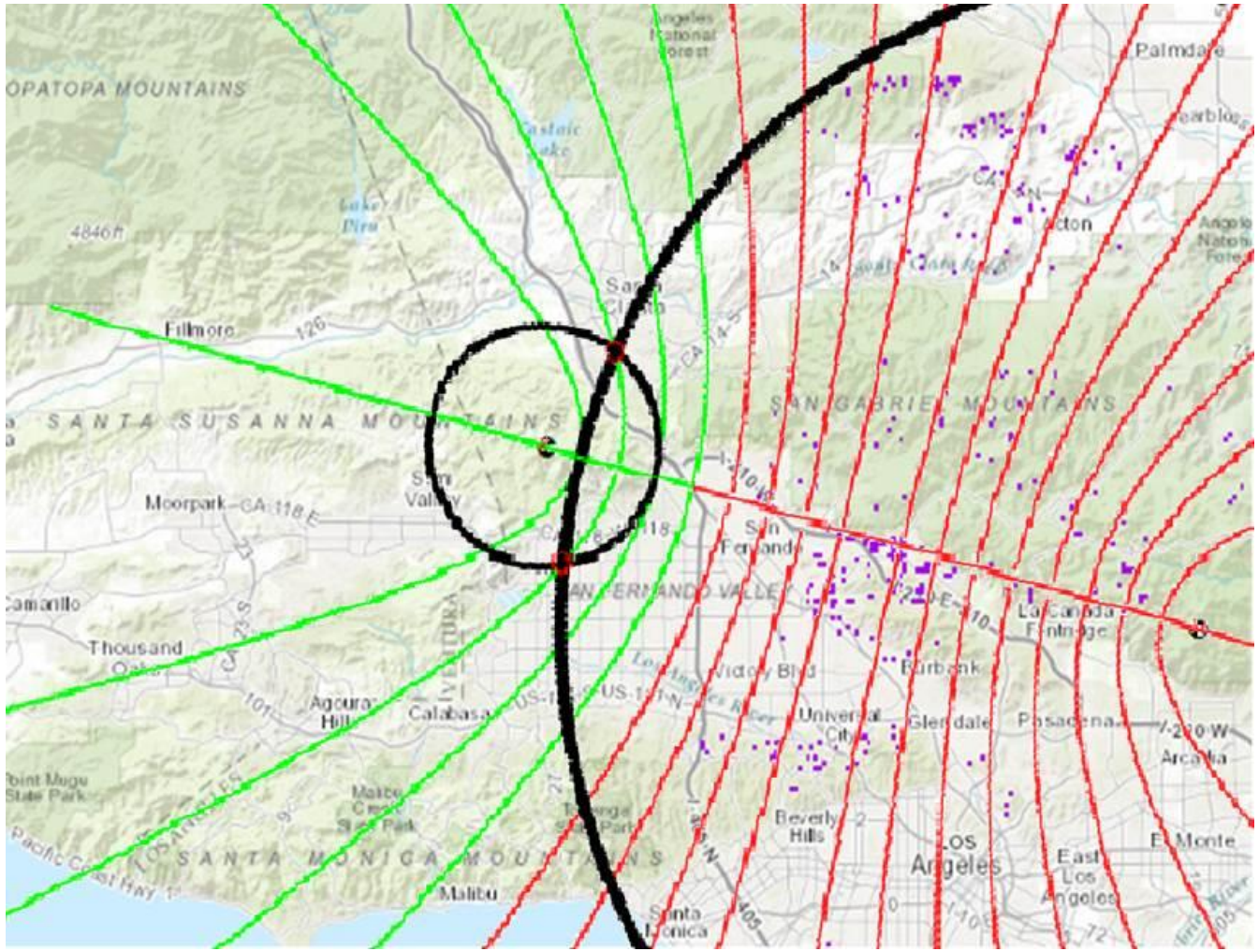
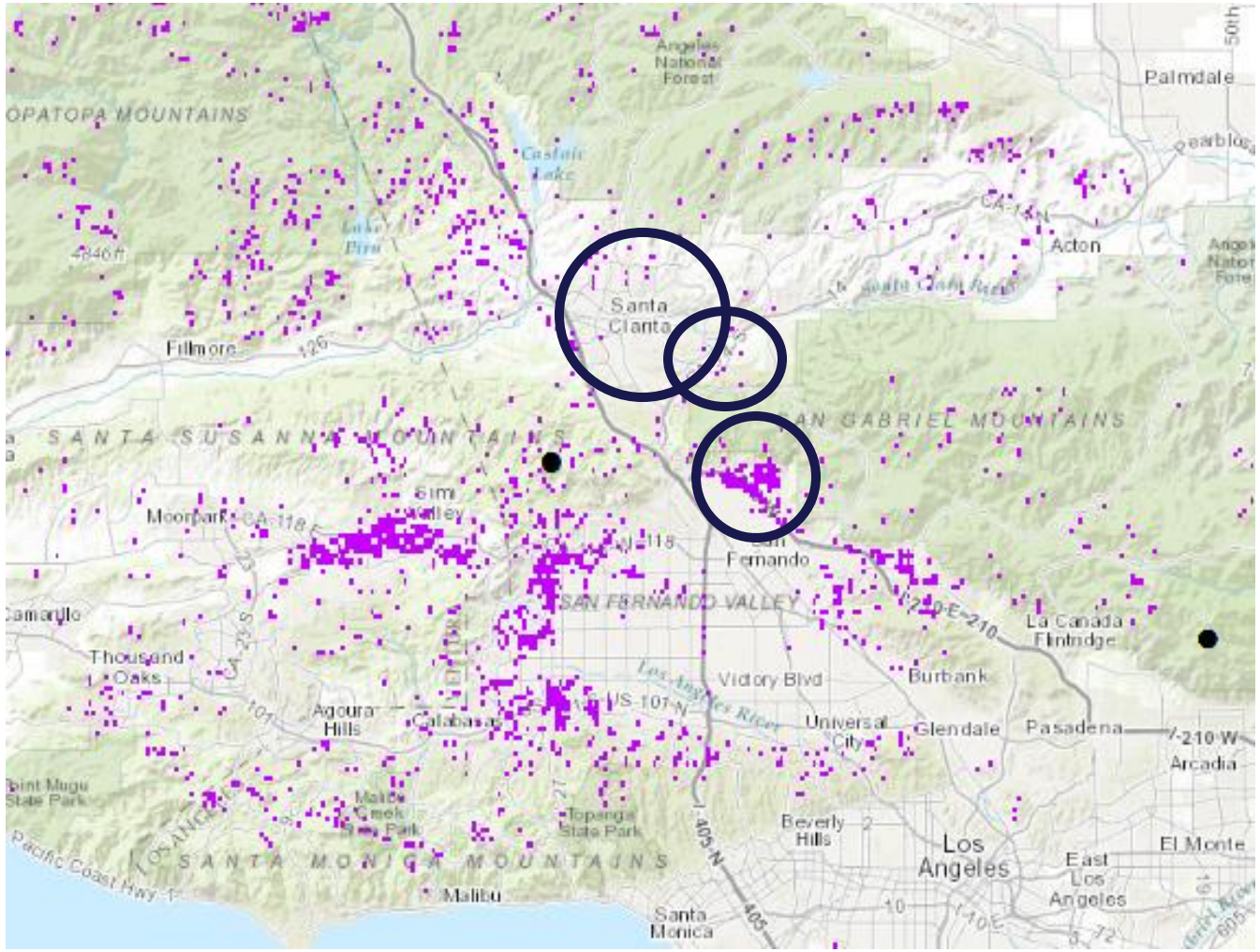
# KUSC multipath effects for HD Radio

- **Unsynchronized HD Radio**
  Predicted digital reception difficulties for present -20 dBc injection on both Main and booster
- **Synchronized HD Radio**
  Flight time to booster 176µs, booster is delayed by 176µs - 40µs
- **Time of Arrival Contours**
  Equal delay is 20µs from booster



## KUSC Drive Test Results
## Thursday Apr 14, 2016

- Tested both -20 dBc and -14 dBc on Booster
- Solid IBOC coverage of Santa Clarita valley
- Good coverage along route 14 in Canyon Country. HD is locked even with severe FM impairment. Intermittent drops only with expected terrain shielding in canyons.
- Only short intermittent drops in Sylmar region only with clear obstruction like underpasses with little signal from either transmitter.
  - Proves IBOC is synchronized
- Significantly impressed with coverage from **2W IBOC transmission** at 3000'
- **Test was successful**: HD Boosters are an effective option to extend coverage




Thank you Ron Thompson and Tom King of KUSC and John Kean

# Conclusion

- SFNs must be aligned in time within interference zone
  - FM Stereo: Difficult
  - FM Mono: Workable
  - IBOC: Possible, increase coverage seamlessly
- Nautel offers industry first SFN implementation
  - Fixed HD audio throughput delay
  - Align FM with Modulation Monitor
- Nautel has demonstrated seamless HD transitions
- Field trials at KUSC, Los Angeles, are a success

# Limited Release Participation

**Interested in helping out with limited release HD SFN if we do one?**

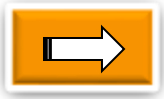
**Send your contact details and station profile to:**

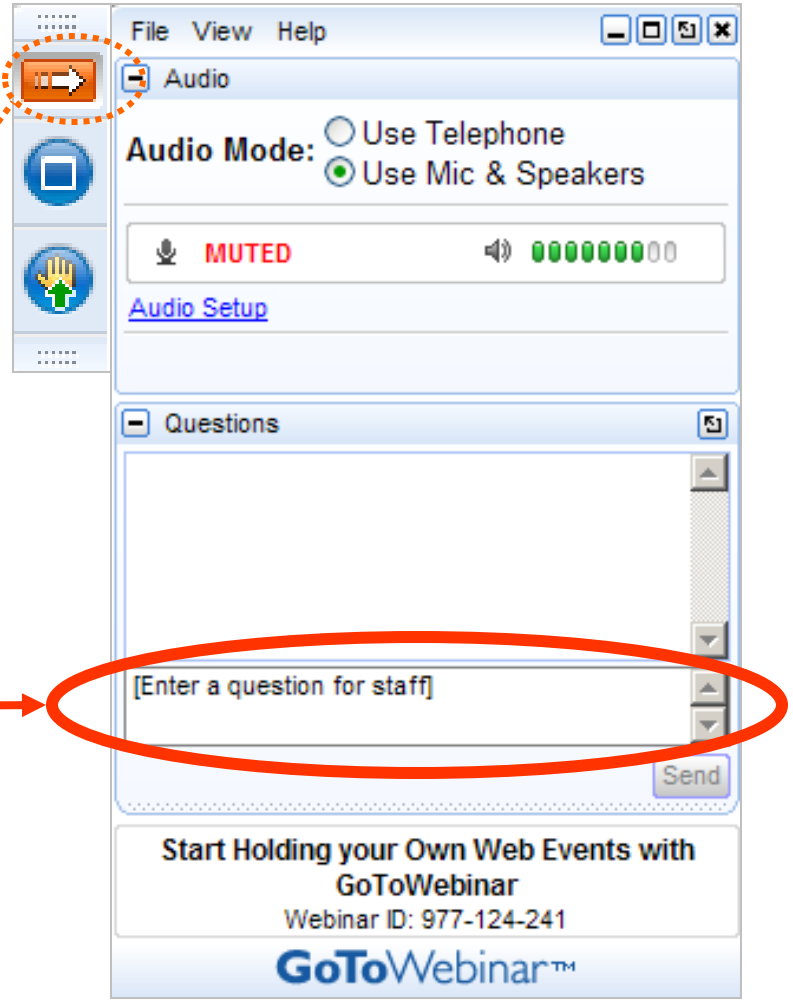
**Matt Herdon, Product Manager**
matt.herdon@nautel.com

# SUPPORT MATTERS

## INDUSTRY'S #1 SUPPORT

# Questions?

*Click on*  *to open/close webinar panel*




*Enter questions here*
*…then press* **Send**

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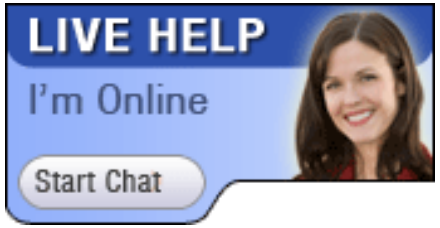
  http://www.youtube.com/user/NautelLtd

# We're here to help

sales@nautel.com

www.nautel.com




**Chuck Kelly**

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48 years of NAUTEL 1969 2017

nautel

making digital broadcasting work

# Thank You

# Limited Release Participation

If you are interested in participating in a limited HD SFN release please contact Nautel and tell us about your site, why it would benefit from HD SFNs and whether you already have an RF consultant lined up to work with you.

Please take a moment to complete our survey at the end of this webinar. Thank You.


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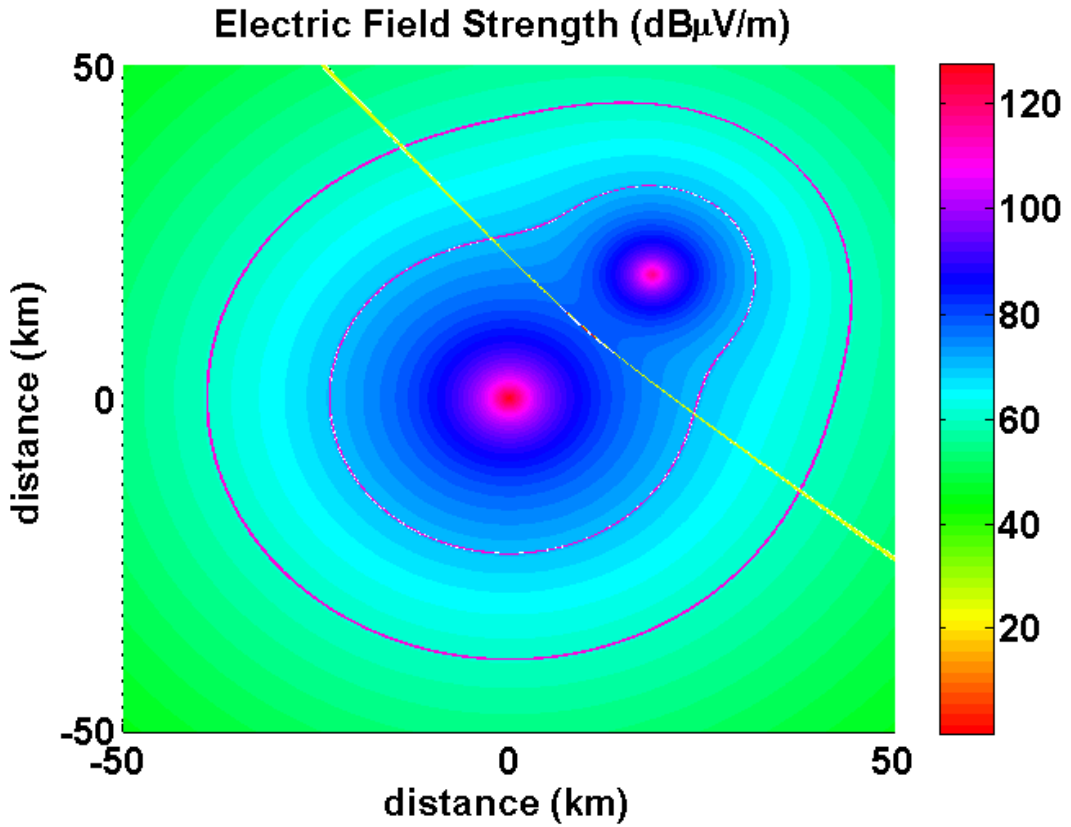
# Elevated IBOC Power Levels

Hybrid FM+IBOC System
- Primary 2.5 kW IBOC at -10 dBc injection
- Booster **250 W IBOC at 0 dBc** injection

No **interference** (7 dB D/U)
- Booster increases **city grade contour**
- Big increase in combined **60 dBu contour**

39 µs booster time advance
- Eliminates back end interference entirely
- Booster delay 87.3 µs – 40 µs = 47.3 µs
- Meets primary wave 20 µs or 6 km out

**40 µs timing margin** provides large buffer
- Extended seamless coverage is possible



# Booster Elevated IBOC Power Levels

Increase IBOC to 0dBc injection? **Yes**

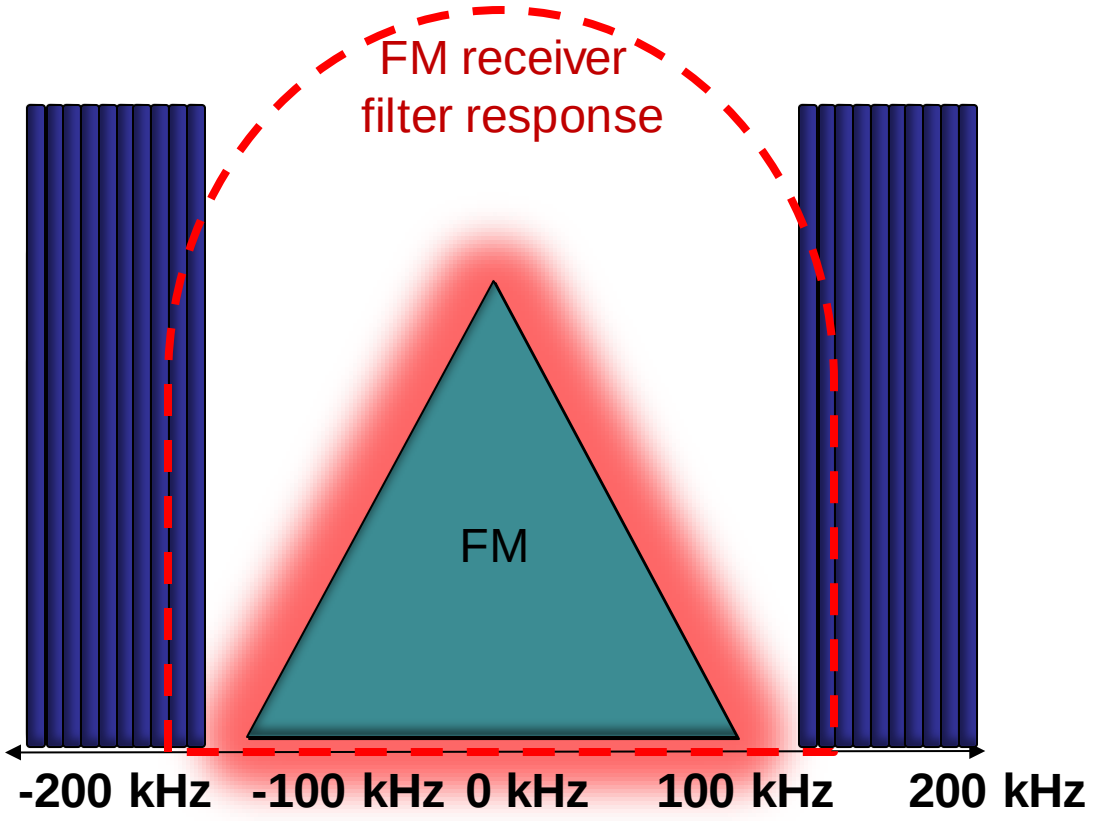
- Smaller FM interference region
- Large IBOC coverage
- Place booster closer to protected contour
- Tests conducted at WD2XAB Baltimore

Increase IBOC higher? **Caution**

- Risk to drown out FM receivers close by
- FM receiver selectivity captures IBOC
  - 20 dB bandwidth ~260-500 kHz

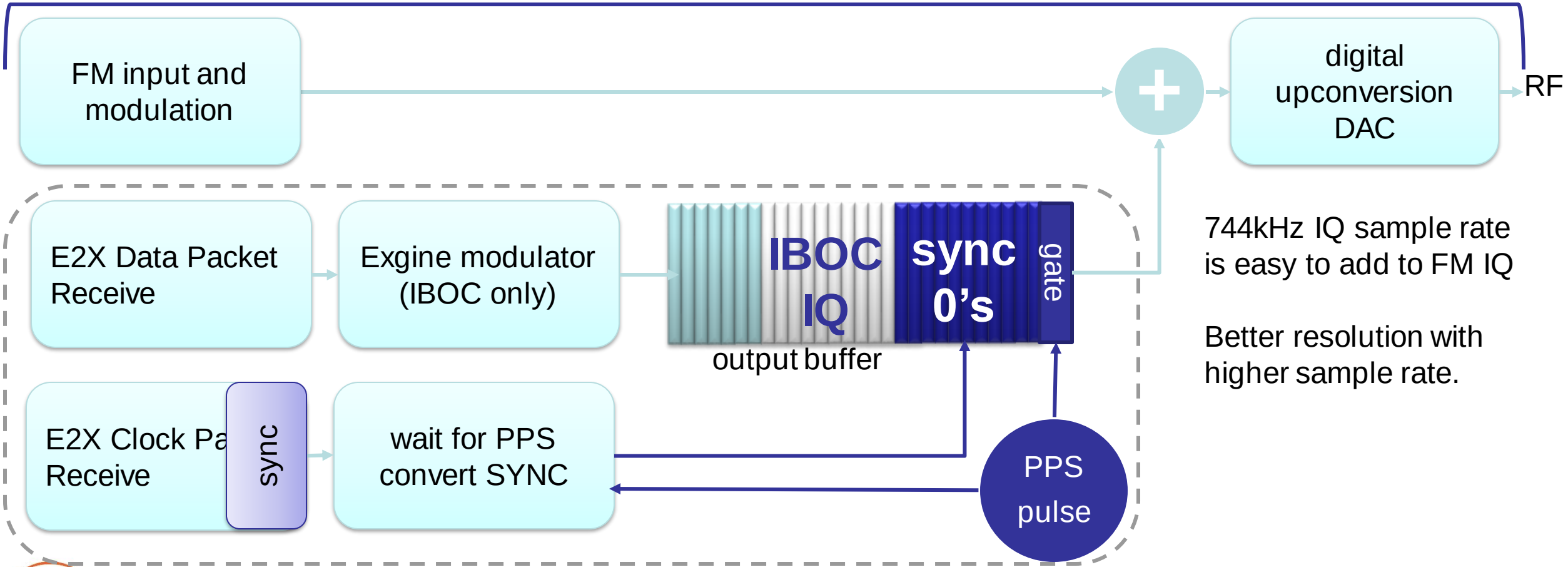
IBOC only boosters? **No for hybrid FM+HD**

- Future application in all-digital operation



# Exciter Synchronization

Required: fixed FM analog delay




744kHz IQ sample rate is easy to add to FM IQ

Better resolution with higher sample rate.

# Synchronizing E2X Packets

| | Byte 0 | Byte 1 | Byte 2 | Byte 3 |
|---|---|---|---|---|
| Word 0 | res | res | Audio Count | |
| Word 1 | Transmit GPS Timestamp (opt) | | | |
| Word 2 | res | res | res | res |
| Word 3 | res | res | res | res |

- Sync words available since IRSS 4.3.2 (2010 Gen 3 Exporter / Exgine)
  - Passed to exporter audio msg
  - Included in E2X clock packet
- L1 Frame alignment (ALFN) is possible by starting the exporter on an L1 boundary (optional)
  - ALFN 0 was transmitted 00:00:00 UTC on January 6, 1980
  - Exporter must compute L1 frame boundary in the future

**Audio Count**: count of first 44.1 kHz audio sample since last PPS appended to exporter audio message of 4096 samples.
**Transmit GPS Timestamp** (optional): The PPS after which this audio message is to be sent.