

FM-IBOC Broadcast Systems Architecture Considerations for Single Frequency Networks

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Presentation Outline



- Introduction
- KCSN case study
- Need for Hybrid FM+IBOC boosters
- Guidelines for synchronous IBOC
- Guidelines for synchronous FM
- Nautel SFN Implementation
- Conclusions

What are Single Frequency Networks?

Multiple synchronized transmitters broadcasting on the same channel to provide near seamless coverage.

Why bother with SFNs?

- Terrain shadowing
- Extend coverage
- Spectral efficiency
- Strengthen IBOC
- Protect coverage
- Underground (tunnels)

The Challenge

Define, manage and control the mutual interference zone across multiple transmitters.

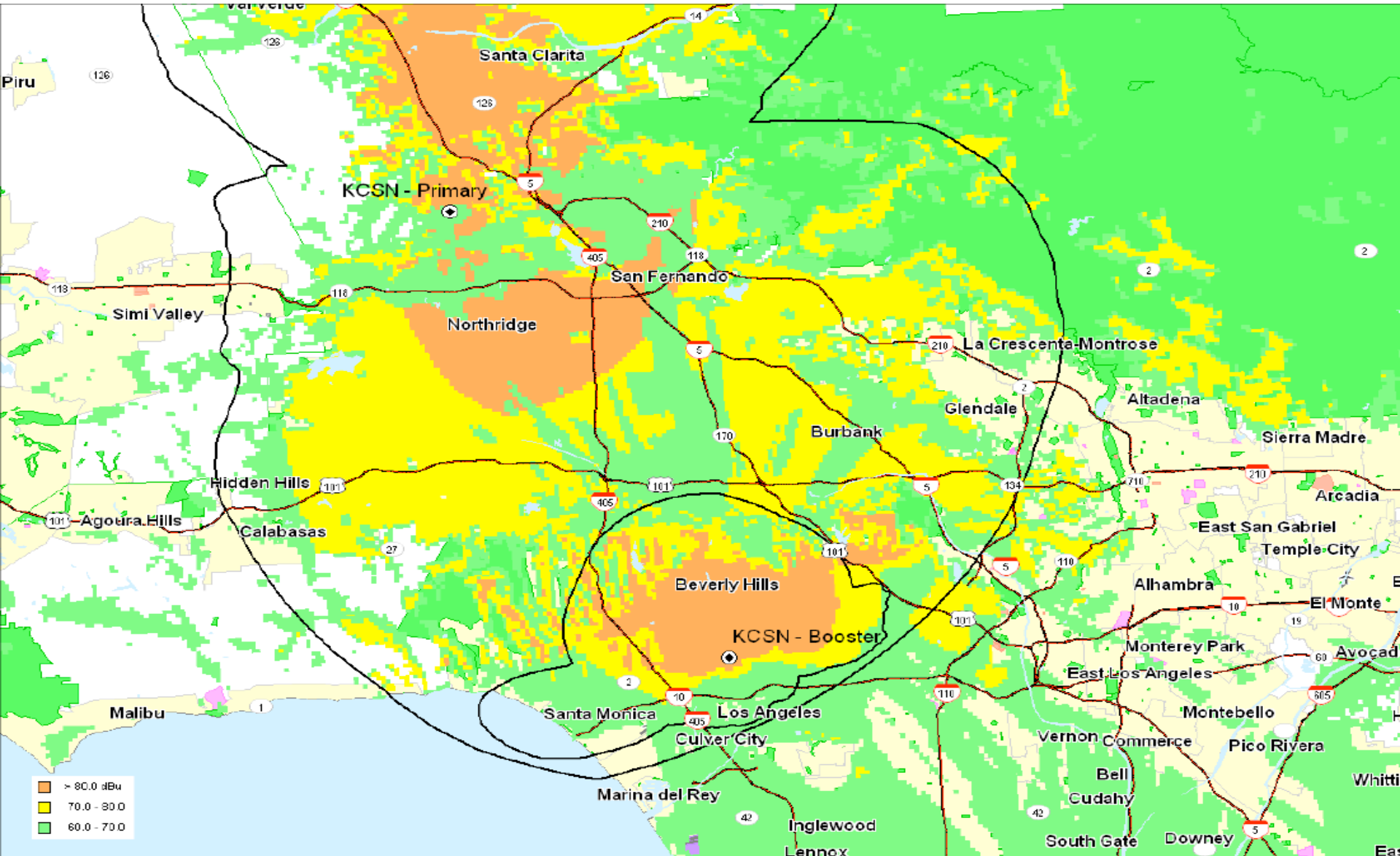


KCSN Overview

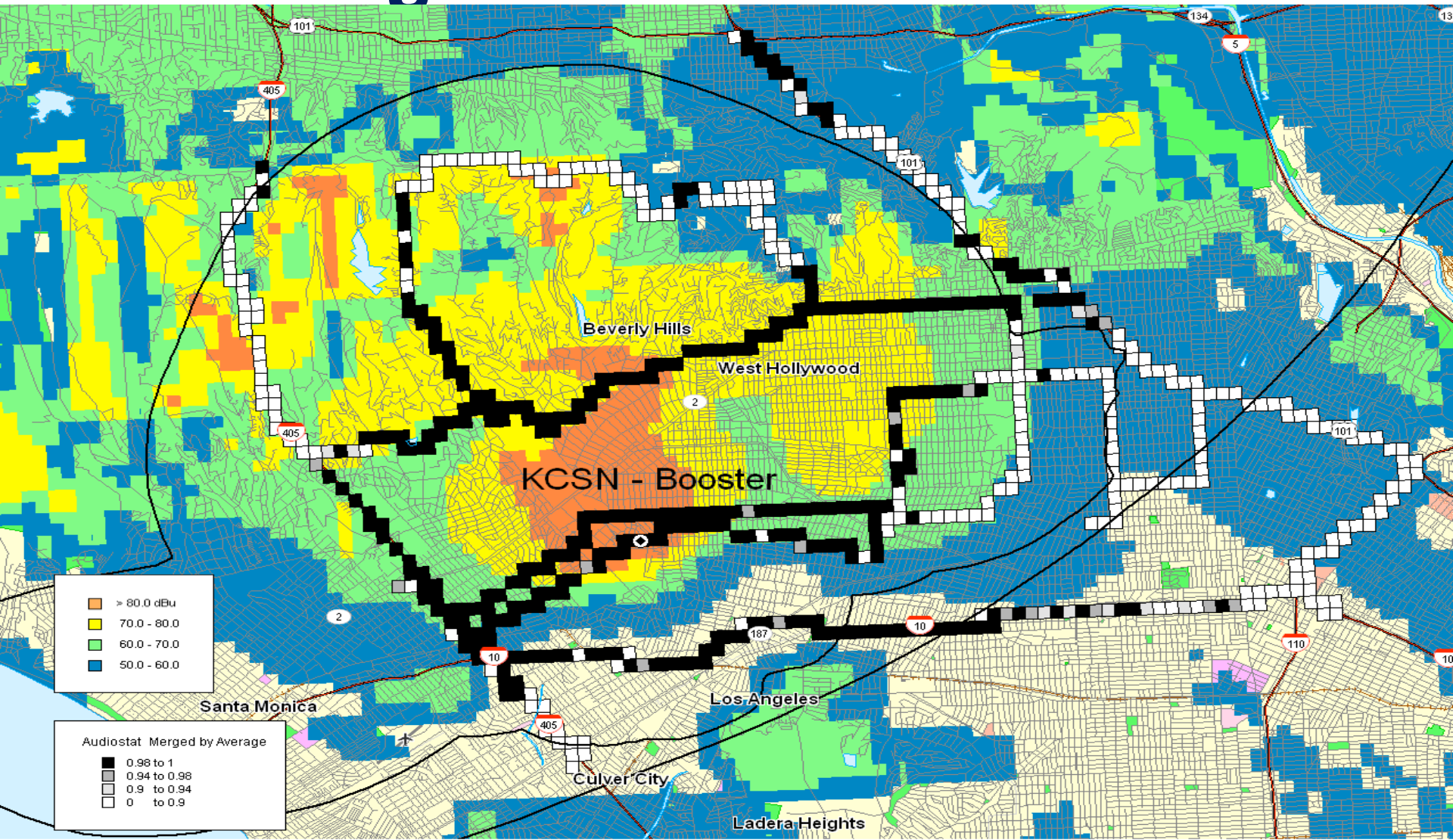


- California State University, Northridge CA
- NPR Booster Field trials in December 2004
- Terrain shadowing (Santa Monica Mountains)
 - KCSN-FM1 booster in Hollywood
- Hybrid FM+IBOC booster
 - 38 km apart (127us)
- Effective coverage around booster
- Reduced IBOC reception in interference zone
 - Requires timing control
 - Requires identical modulation

KCSN Coverage



KCSN IBOC Coverage



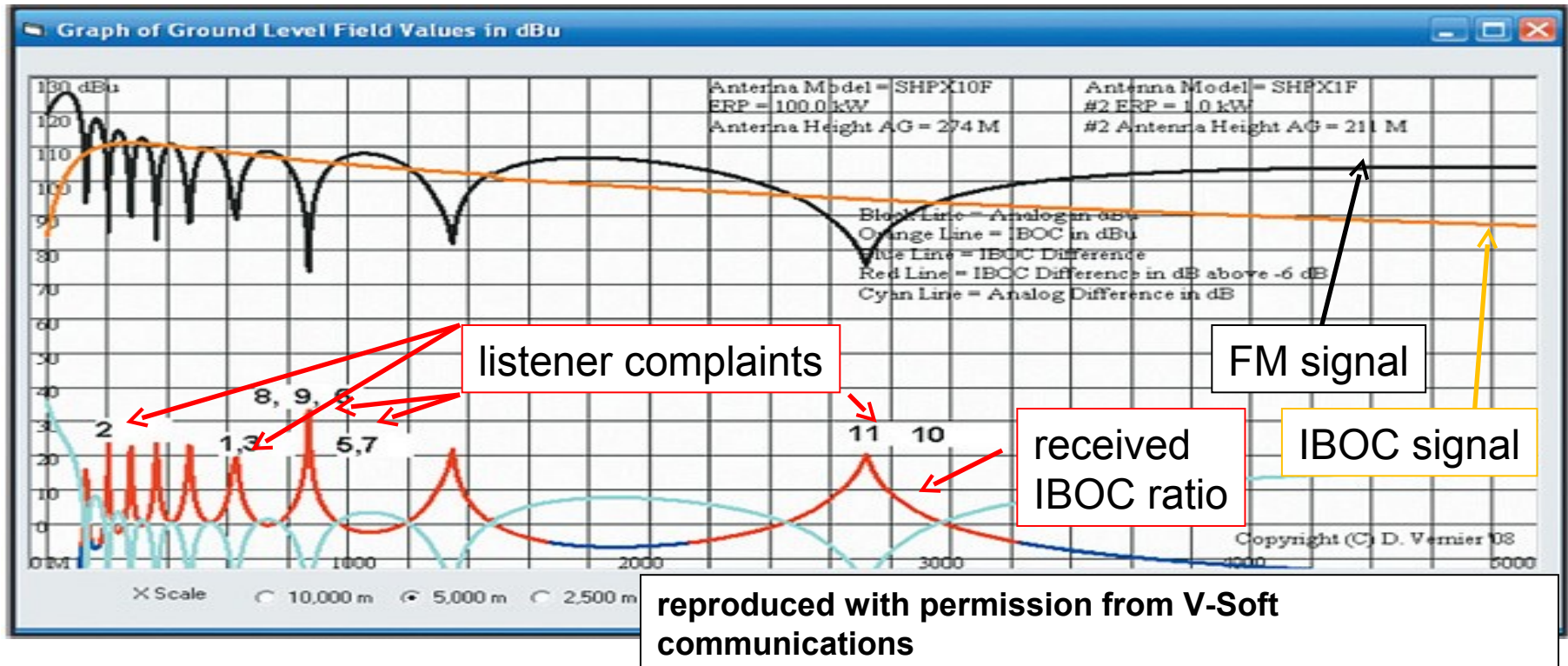
KCSN Conclusions



- Precise time alignment control
 - Requires IBOC L1 frame alignment across IBOC modulators
 - All FM modulating inputs are synchronized
- Precise modulation control
 - Identical IBOC output in all cases
 - FM 19 kHz tone synchronization
- Cost effective solution
 - Address FM and IBOC

Digital Host Interference

Space Combined System

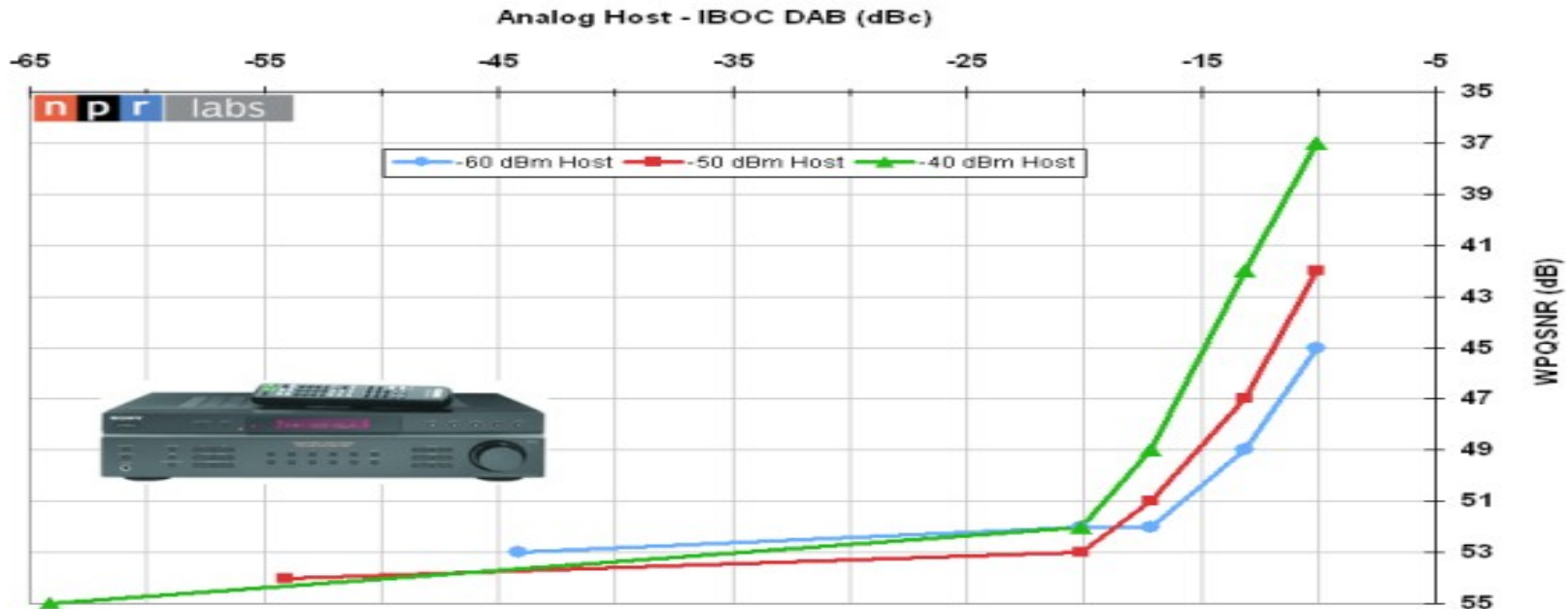


- “The Looming Danger of Digital Host Interference” by Doug Vernier (Radio World)

Digital Host Interference

- Good FM audio at -20 dBc IBOC carriers
- Additional noise with IBOC carrier increase
 - Receivers designed with 6 dB 1st adjacent DU ratio
 - Maintain FM signal in on-channel booster to ensure good DU ratios
- Highly receiver dependent
 - NPR Labs to test more receivers (advanced IBOC interference study)

Audio SNR vs. IBOC Ratio: Sony STR-DE197 Component Stereo Receiver



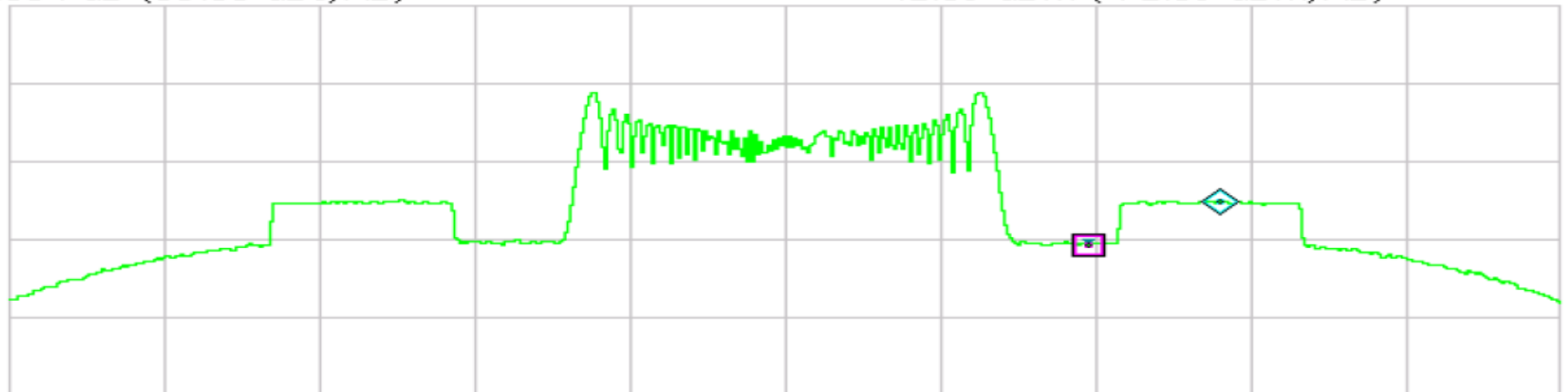
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IBOC SFN Requirements

- 75 μ s time alignment main to booster (± 20 dB)
- 1 μ s time IBOC L1 frame alignment on all TX (debatable)
- Intermittent IBOC reception (without interferer):
 - -20 dBc: 40-50 dBu -10 dBc: 30-40 dBu
- 5 dB required to receive IBOC HD-1 in AWGN
 - Uncoded bit error rate around $7E-2$

$\Delta 1-2$: 50.87890625 kHz
5.354 dB (35.35 dBc/Hz)

Marker: 106.0169921875 MHz
-42.59 dBm (-72.59 dBm/Hz)

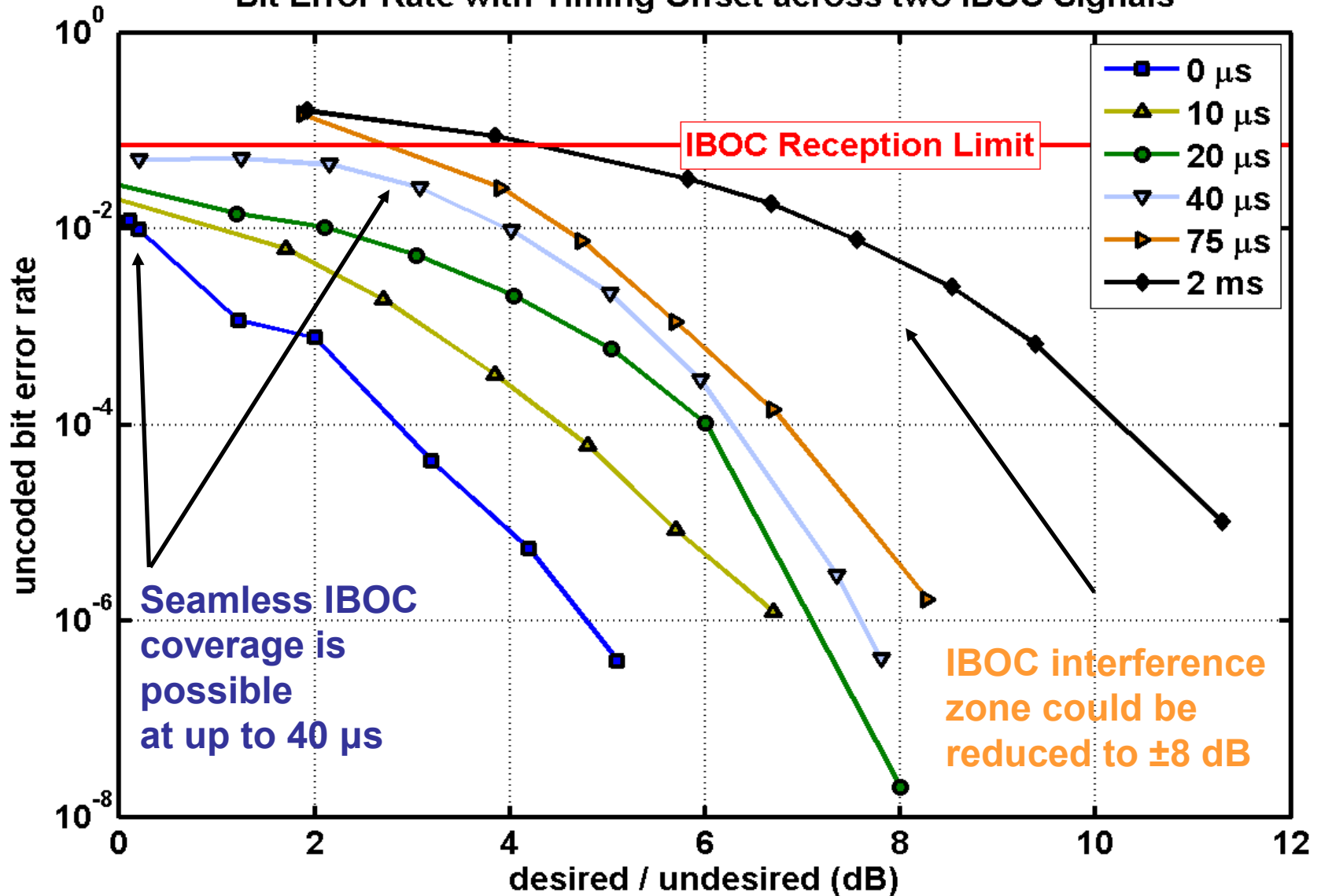


Center: 105.9 MHz

Span: 600 kHz

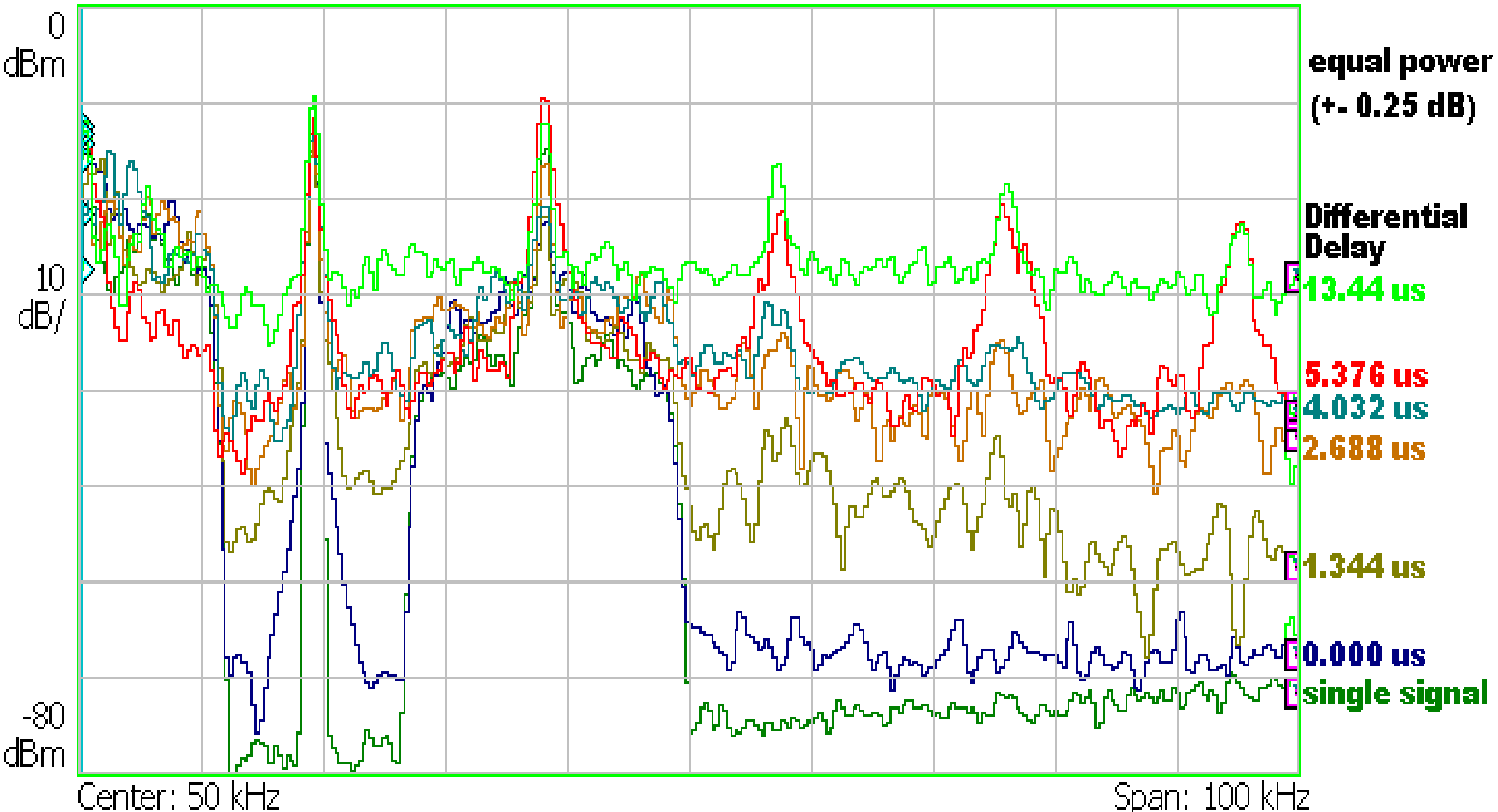
SFN Bit Error Rate

Bit Error Rate with Timing Offset across two IBOC Signals



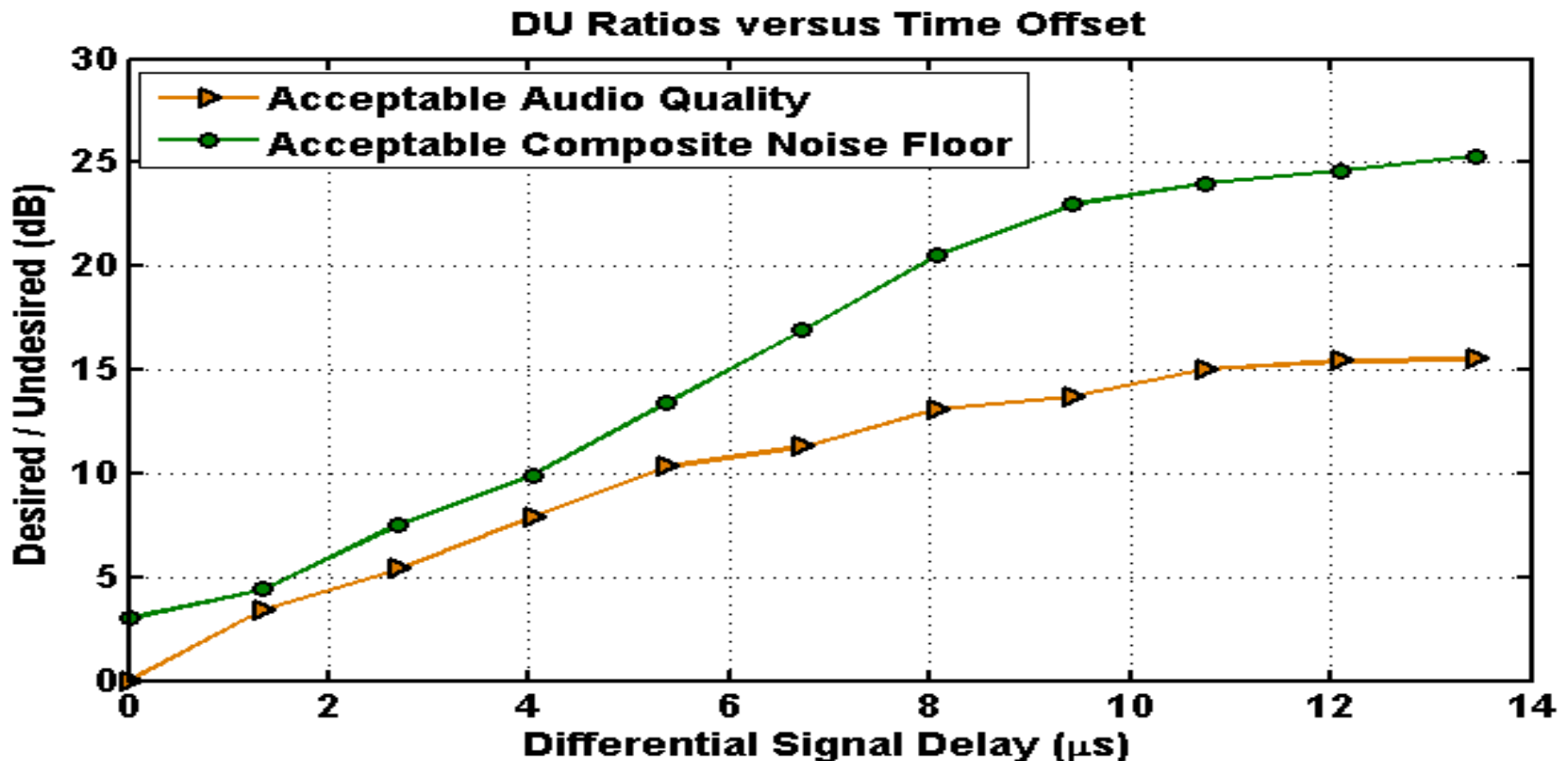
Synchronous FM Interference

Dual Transmitter Demodulated FM Composite Audio Spectrum



Synchronous FM Interference

- Rough guidelines for initial planning
- Audio quality results are highly subjective
 - Treat as preliminary results
- 31 dB co-channel analog-analog interference (NPR Labs)

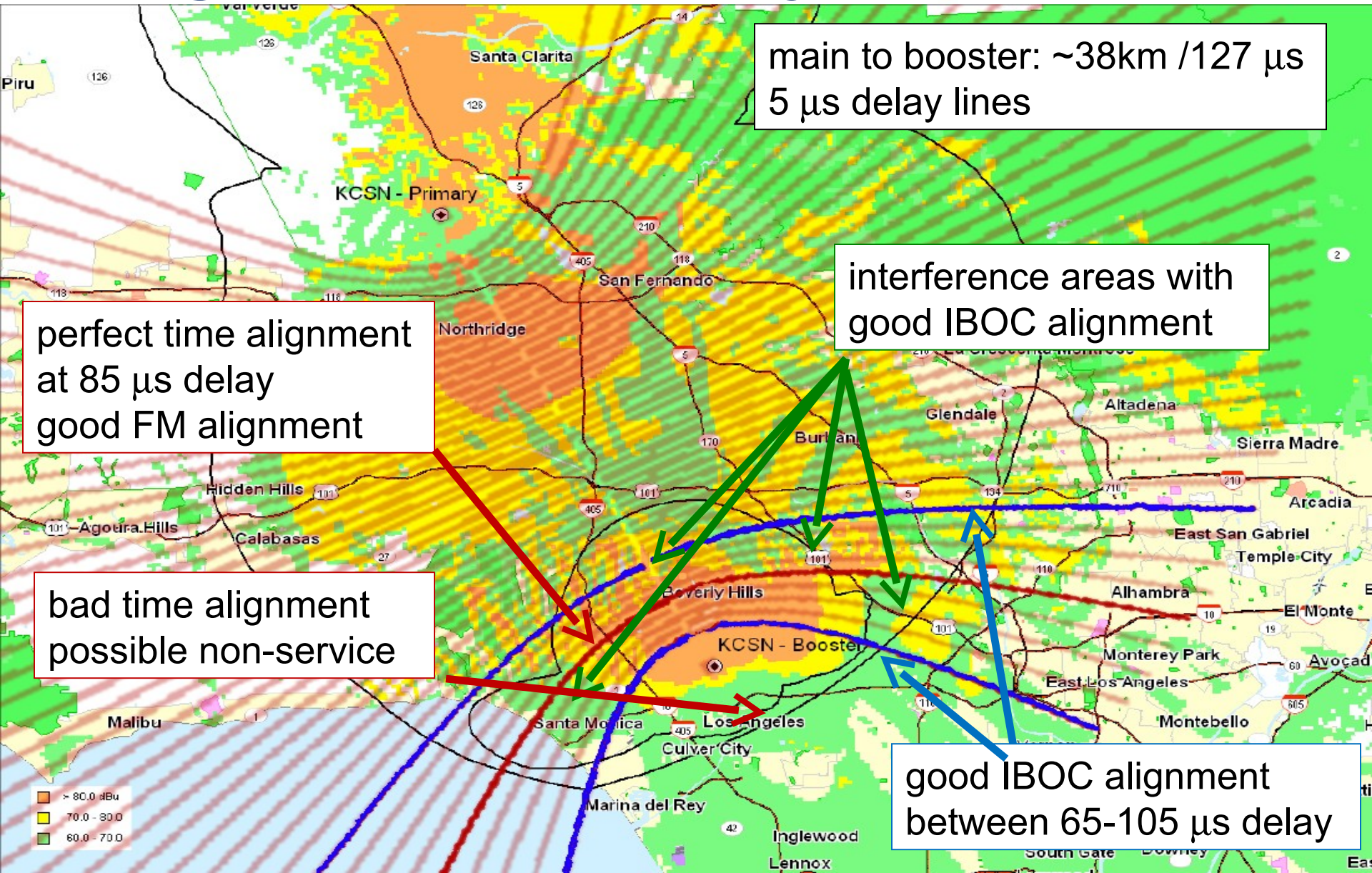


Constant Delay Lines



- 50 km separation
- 167 μ s flight time to cross
- 60 μ s booster delay
- Match equal power to constant delay lines
 - Directional antennas?
- Signal propagation software
 - Time delay interference
- Off-air transmission equal delay on main-booster line

Signal versus Delay



Modulation Control



$$s(t) = A(t) \sin(\omega_c t + \phi(t)) = I(t) \cos(\omega_c t) + Q(t) \sin(\omega_c t)$$

$$s(t) = \Re ((I(t) + jQ(t))e^{-j\omega_c t})$$

IQoverIP: one FM+IBOC modulator, synchronize output

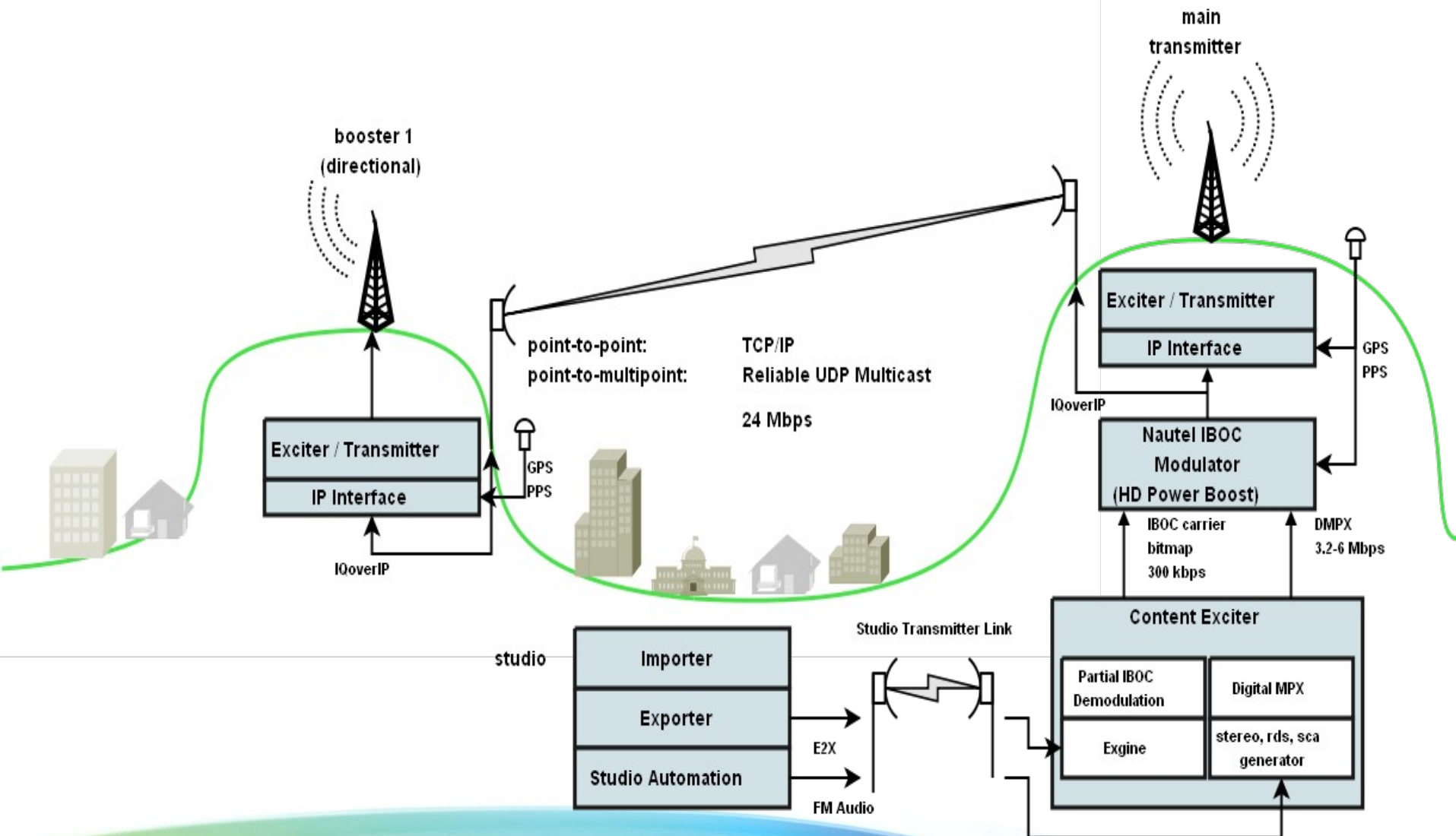
- Digital IQ over IP delivered across RF link
- Complex in-phase and quadrature valued is digitized
 - Mathematically exact signal copy on all exciters
 - Identical FM modulation
 - No pilot tone synchronization
 - Automatic sub-carrier synchronization
- Channel modulation remains at exciter
- Method is modulation agnostic

Timing Control

Single signal stream to synchronize:

- System is GPS synchronized (1 PPS)
- IBOC base sampling rate at 744187.5 Hz
- IBOC samples align with 1 PPS every 2nd second
- Modulator starts new booster on 2 second boundary
- Booster requires precise timing
 - On new signal stream, holds samples until next 1 PPS
 - Timing control through GPS disciplined phase locked loop
 - Sub-microsecond resolution
- Modulator timing requires no precision
 - Avoids race conditions on start-up

IPoverIQ Overview



Booster Components



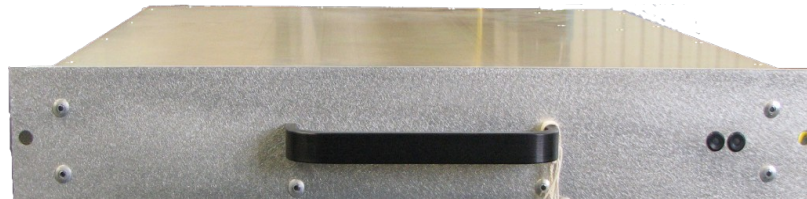
MicroWave
Transmission
System
34 Mbps



FM broadcast
antenna of choice



GPS Receiver
and Antenna
(1 PPS source)



Nautel 300 W NVE Standalone
Exciter (optional transmitter)

Cost Effectiveness




- Link bandwidth versus complexity tradeoff
 - No Exgine IBOC exciter at booster
 - No FM modulator at booster
 - No stereo, RDS, SCA generators at booster
 - No pilot tone synchronization
 - Single signal stream to synchronize
- Requires high bandwidth IP link
 - Investigate IQ stream compression
 - Transfer IBOC carrier bitmap and digital MPX
- Nautel HD Power Boost on all boosters
 - IQ stream incorporates HD Power Boost
 - More power for each booster (exciter only options)
 - No HD Power Boost modulator at booster

Conclusions

- Hybrid FM+IBOC boosters needed to protect FM
- Seamless IBOC coverage through SFNs is possible
- FM SFNs require careful management
 - We cannot do better than FM multi-path
- IQoverIP technology provides
 - Identical modulation across booster and primary
 - Precise time control with sub microsecond resolution
 - Simplifies booster deployment and cost

Future Work

- Need a model to evaluate benefits of booster deployments
 - Investigate higher IBOC injection for booster only
- 

Thank You



Modulation Control

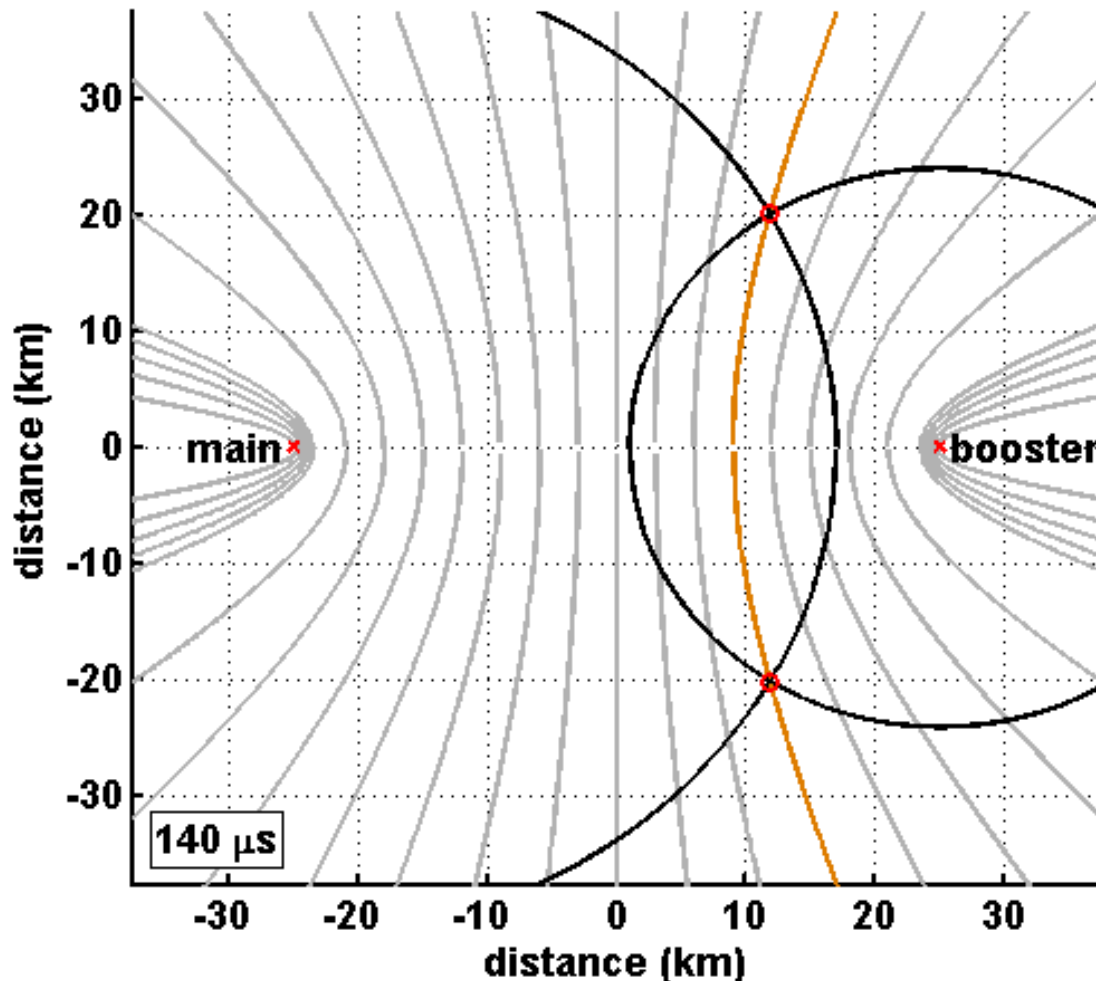


Option 1: N synchronous modulators

- Synchronize N IBOC modulators to GPS
- Fixed audio delay across STL
- Synchronize FM 19 kHz pilot tone phase to GPS
- Identical FM modulation depth and parameters
- What about RDS and SCAs?
 - Distribute analog FM composite
 - Requires identical modulation depth
 - Audible artifacts at 0.2-0.3 dB modulation difference

Constant Delay Lines

Constant Delay Line at 60 μs Transmission Offset



- 50 km separation
- 167 μs flight time to cross
- 60 μs booster delay
- Match equal power to constant delay lines
 - Directional antennas?
- Signal propagation software
 - Time delay interference
- Off-air transmission equal delay on main-booster line