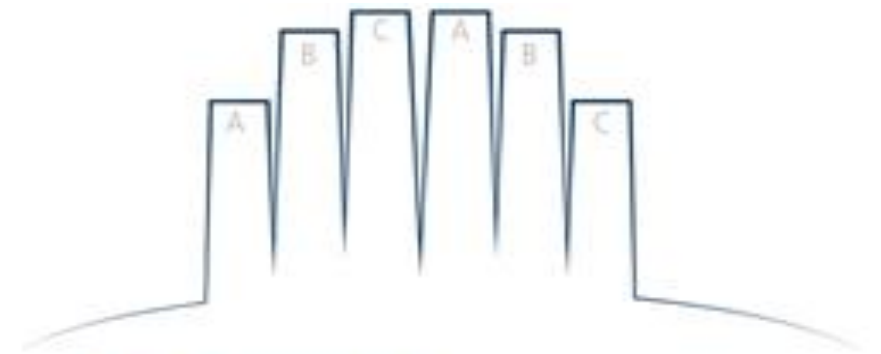


Digitizing Terrestrial Radio with Digital HD Radio Multiplex

A Transition Strategy to All Digital HD Radio Broadcasting

Philipp Schmid
April 16, 2016

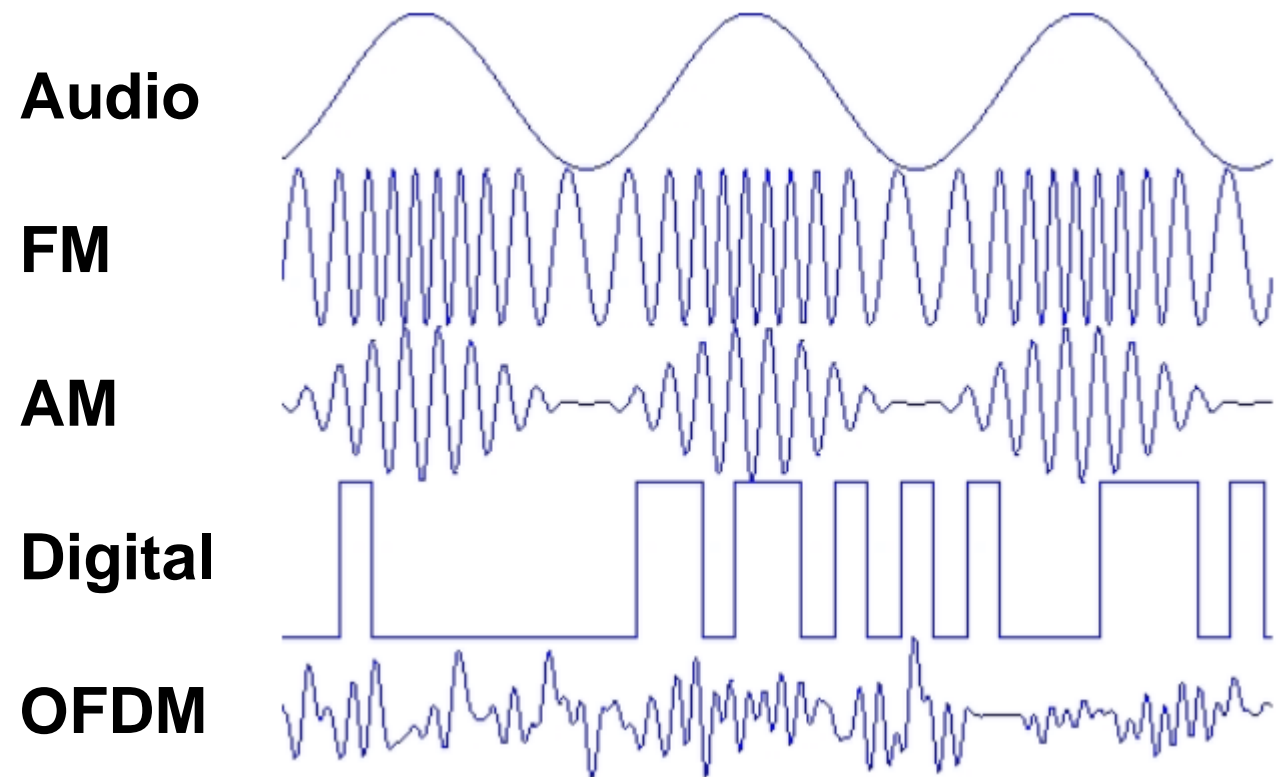


15 Channels in 600 kHz
9 Channels in 400 kHz

All Digital Radio

Broadcast Radio: The last Analog Medium

Why go digital?



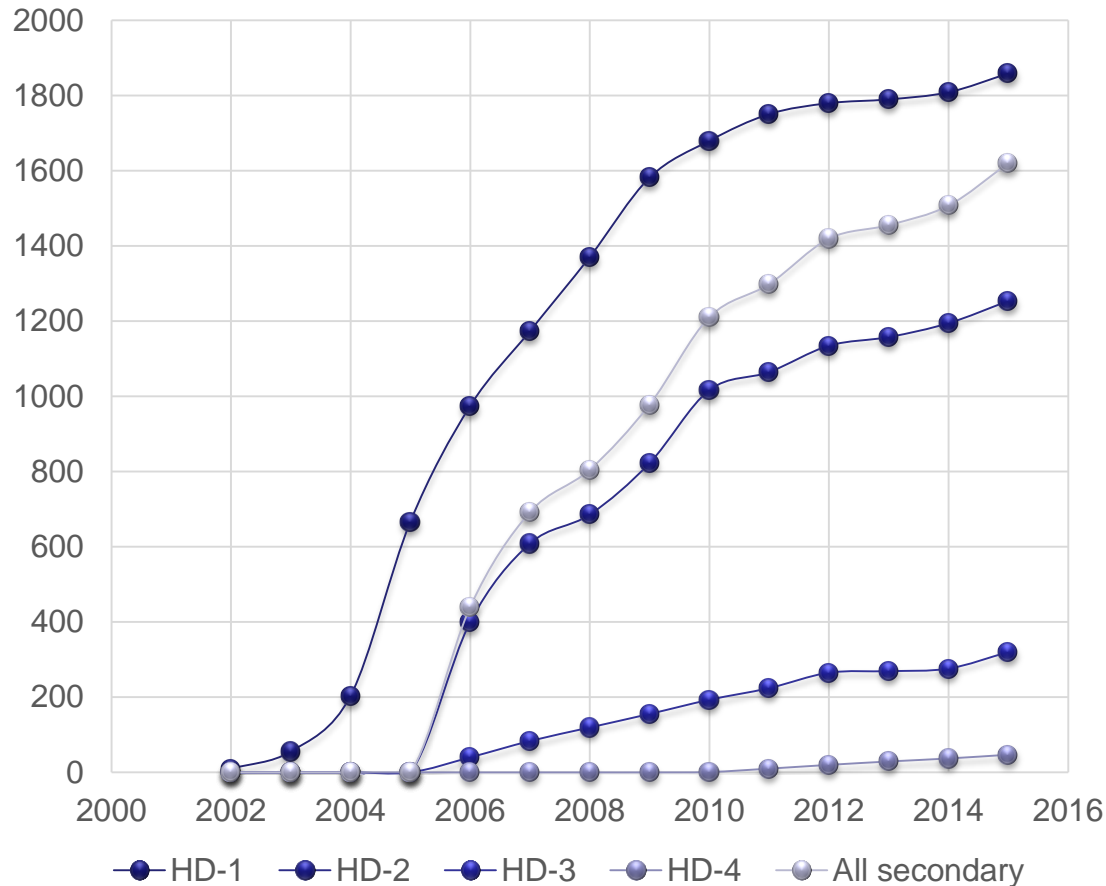
1. Better audio quality
 - Multipath rejection
 - Solid audio ... until the cliff
2. Better spectral efficiency
 - FM band is full in urban areas
 - Multiple audio/data services
 - Lower co-channel protection ratios
3. Lower transmission costs
 - Shared transmission
 - Better energy efficiency
4. Single Frequency Networks

Digital Radio Platforms

- **DAB/DAB+:** Band III (174-240 MHz) or L Band (1,452–1,492 MHz)
 - Multiplex (or ensemble) of audio services (1.2 Mbps in 1.5 MHz)
 - Norway switching national broadcast from FM to DAB+ in 2017
- **Digital TV:** DVB or ATSC
- **DRM:** AM and FM modes
 - Low adoption rate, few receivers
- **Hybrid Radio:** RadioDNS and NextRadio
 - Combines FM broadcast with IP back channel for interactive content
 - NextRadio now available on new Samsung phones
- **Internet Radio**
- **HD Radio™ ...**

HD Radio: Adoption Today

FM IBOC Channels in the US



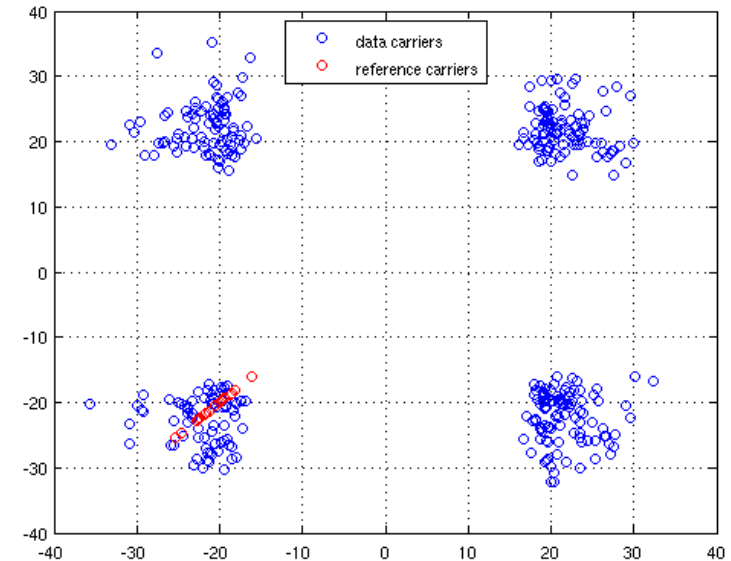
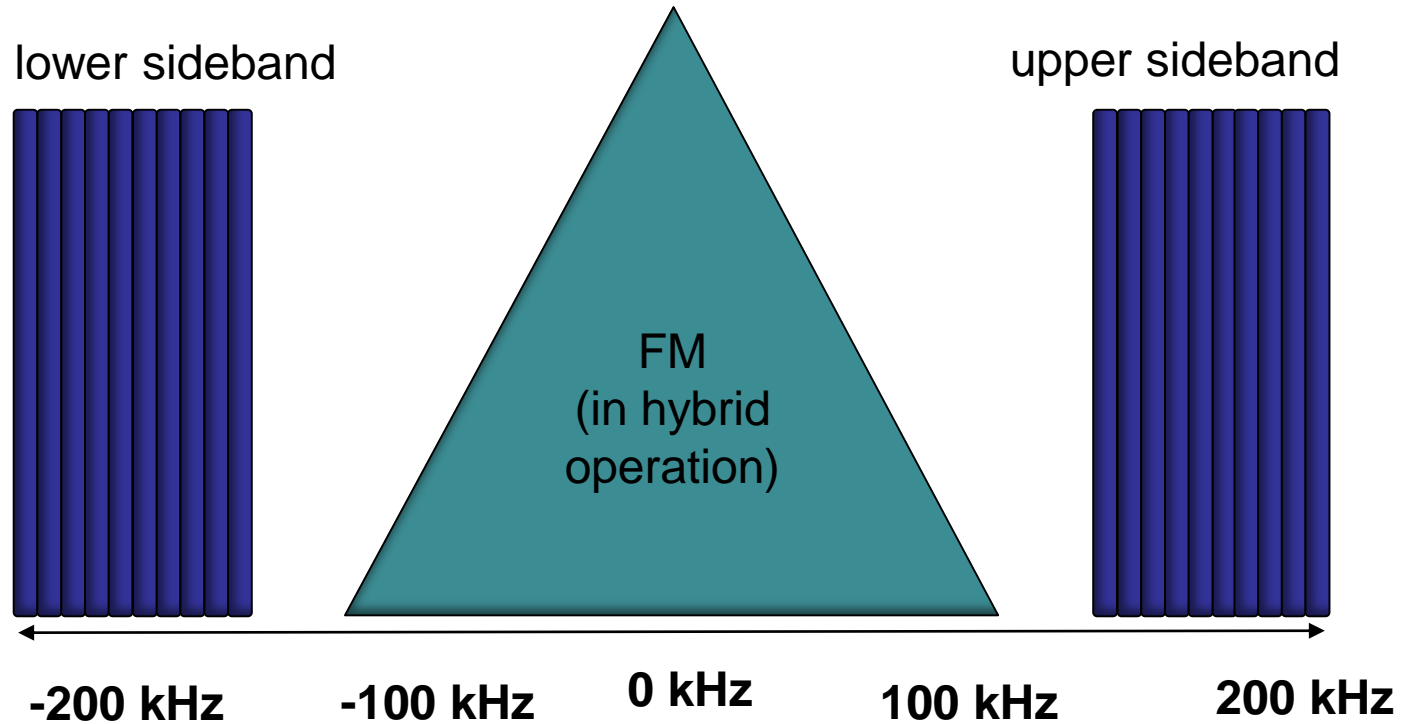
- 2338 stations converted to date
- More HD Radio channels; HD2,3,4 build out
- In 2015, almost 37% of all new cars sold came with factory-installed HD Radio receivers.

Market	HD Radio Channels	Percent cars with HD Radio	Receiver units
New York	122	18.6%	2.3 million
Los Angeles	93	17.2%	2.0 million
Chicago	81	11.4%	844,000
San Francisco	66	14.9%	766,000

current as of December 2015, Source: DTS, Inc. Reproduced with permission.

Hybrid FM+HD adoption is well on its way,
NOW is the time to plan for an **all-digital** future

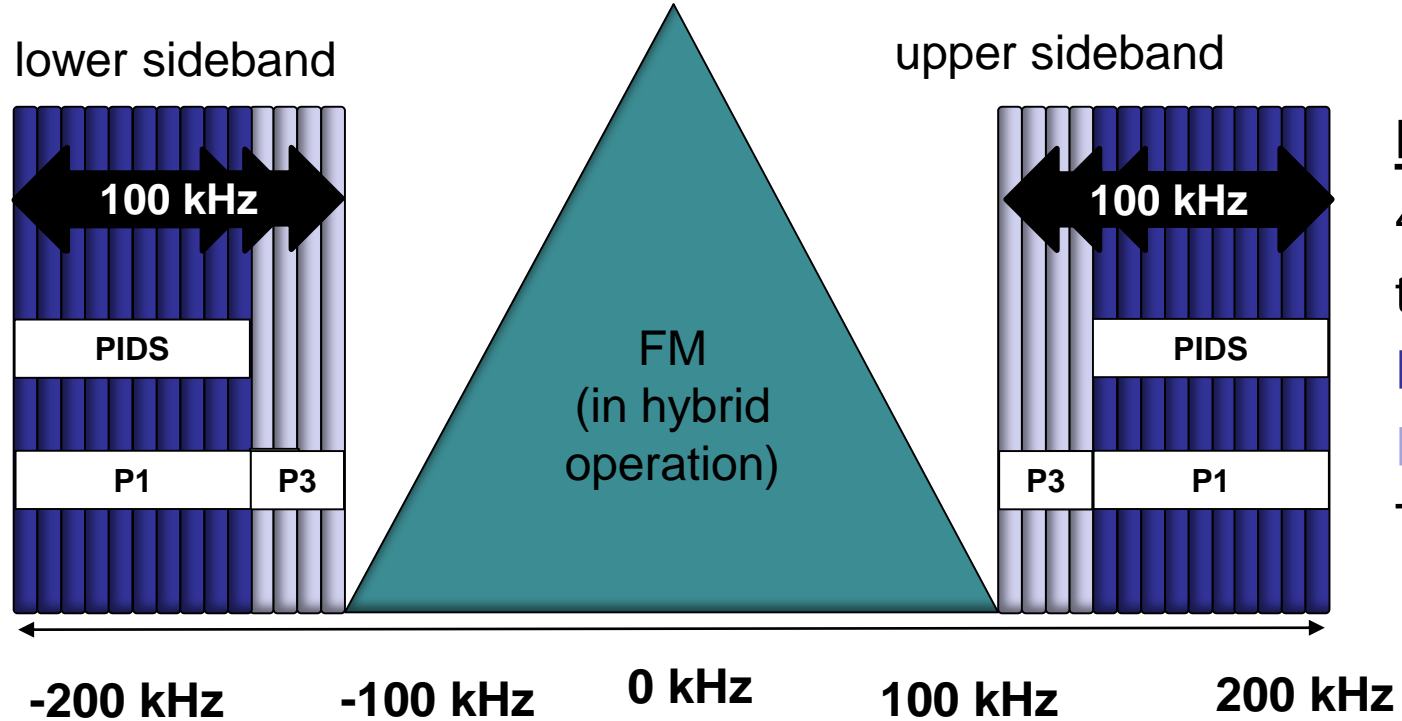
HD Radio: Hybrid IBOC Signal



QPSK constellation

10% IBOC Power \Leftrightarrow FM coverage

HD Radio: Hybrid IBOC Service Modes



Mode MP3

458 carriers

typical 3 audio / up to 5 audio

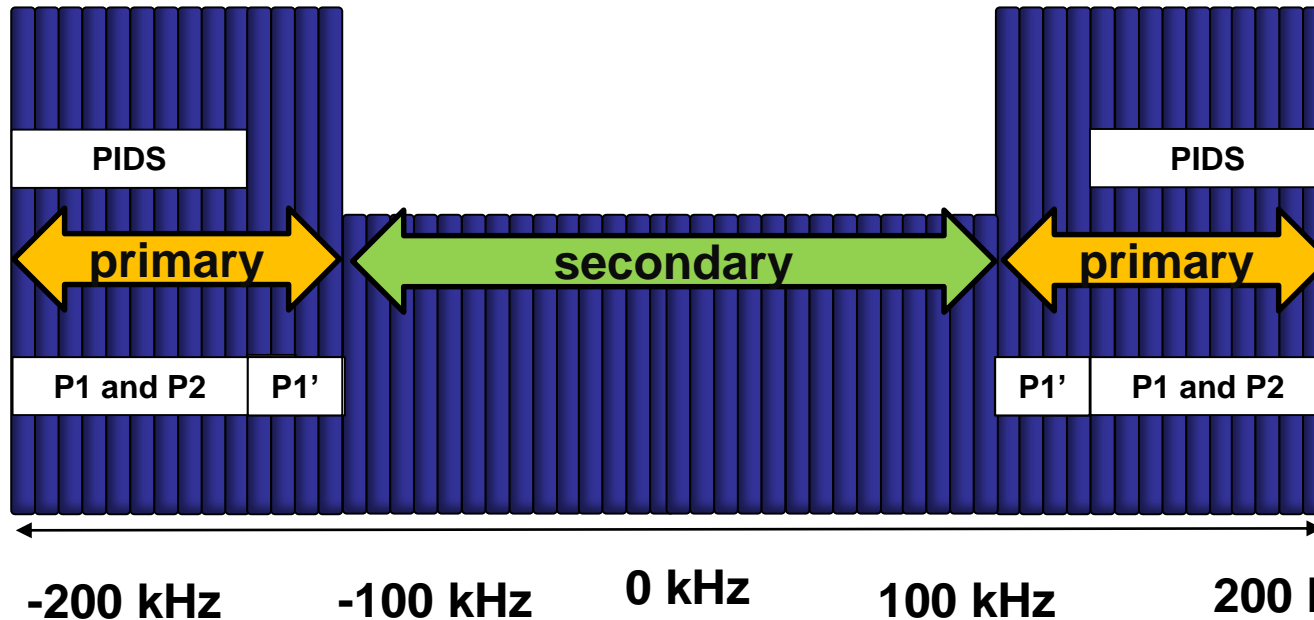
P1: 98.4 kBps

P3: 24.8 kBps

Total 123.2 kBps

- P1,P2,P3 are logical channels with separate FEC
- PIDS: Program Information Data Service

HD Radio: All Digital IBOC Signal



Mode MP6

up to 4 audio

P1: 49.6 kbps

P2: 48.8 kbps

+ Mode MS4

S1: 24.8 kbps

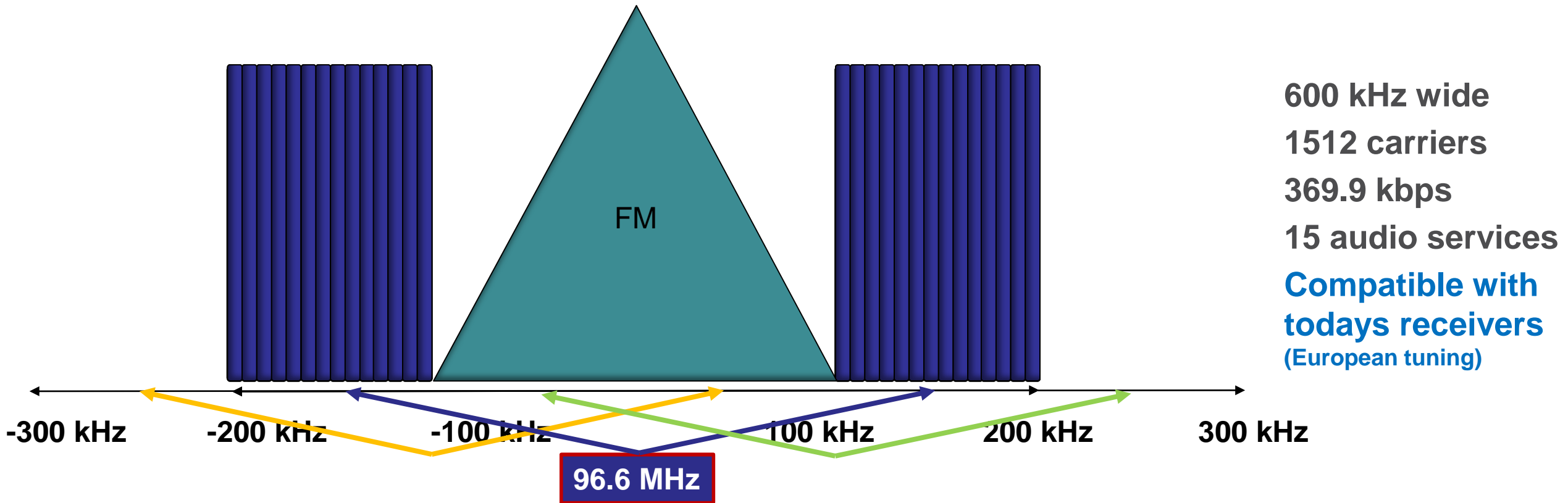
S2: 98.4 kbps

S3: 24.8 kbps

S5: 5.5 kbps

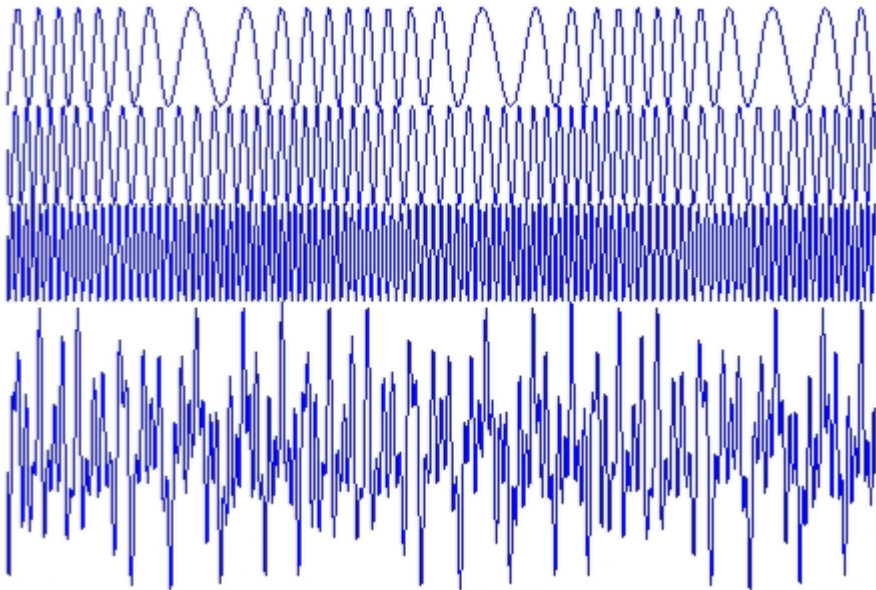
**Secondary MS modes not yet
implemented in transmitters or receivers**

HD Multiplex: Interleaving IBOC Signals



HD Multiplex: Peak Power Reduction

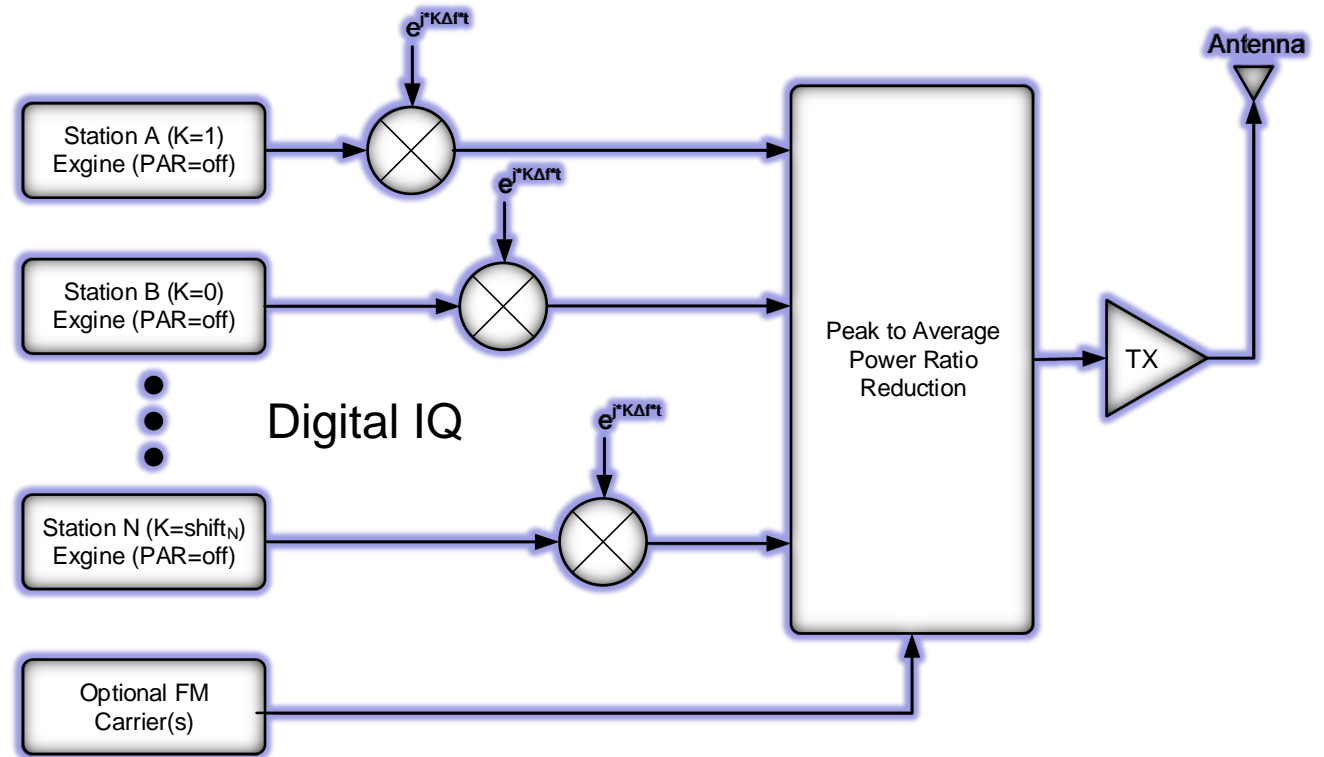
We can't simply combine signals:



(FM shown for illustration)

Simple addition: peak-to-average power increases

$$PAPR_{total}(dB) = PAPR_{single}(dB) + 10 \log N$$



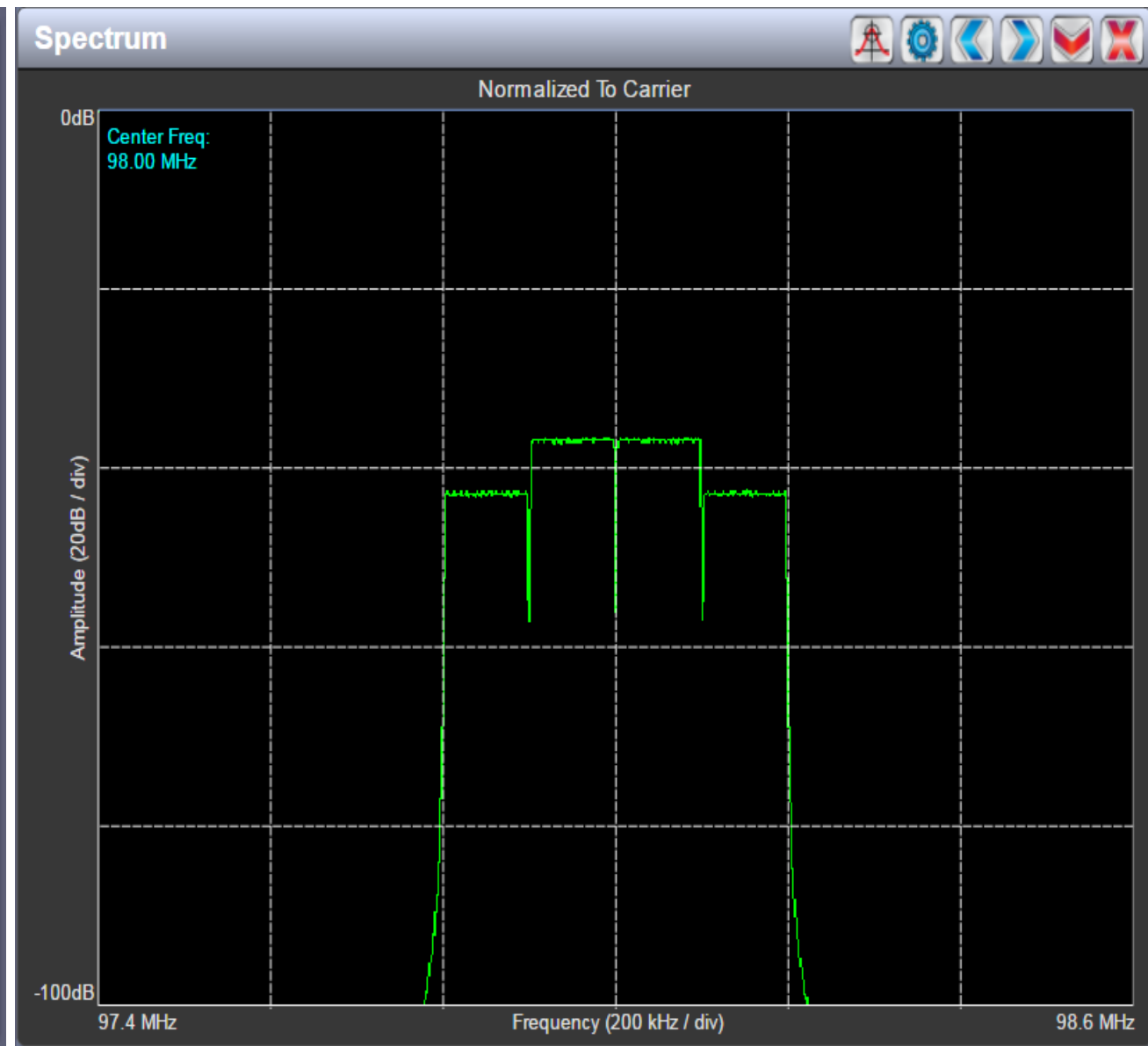
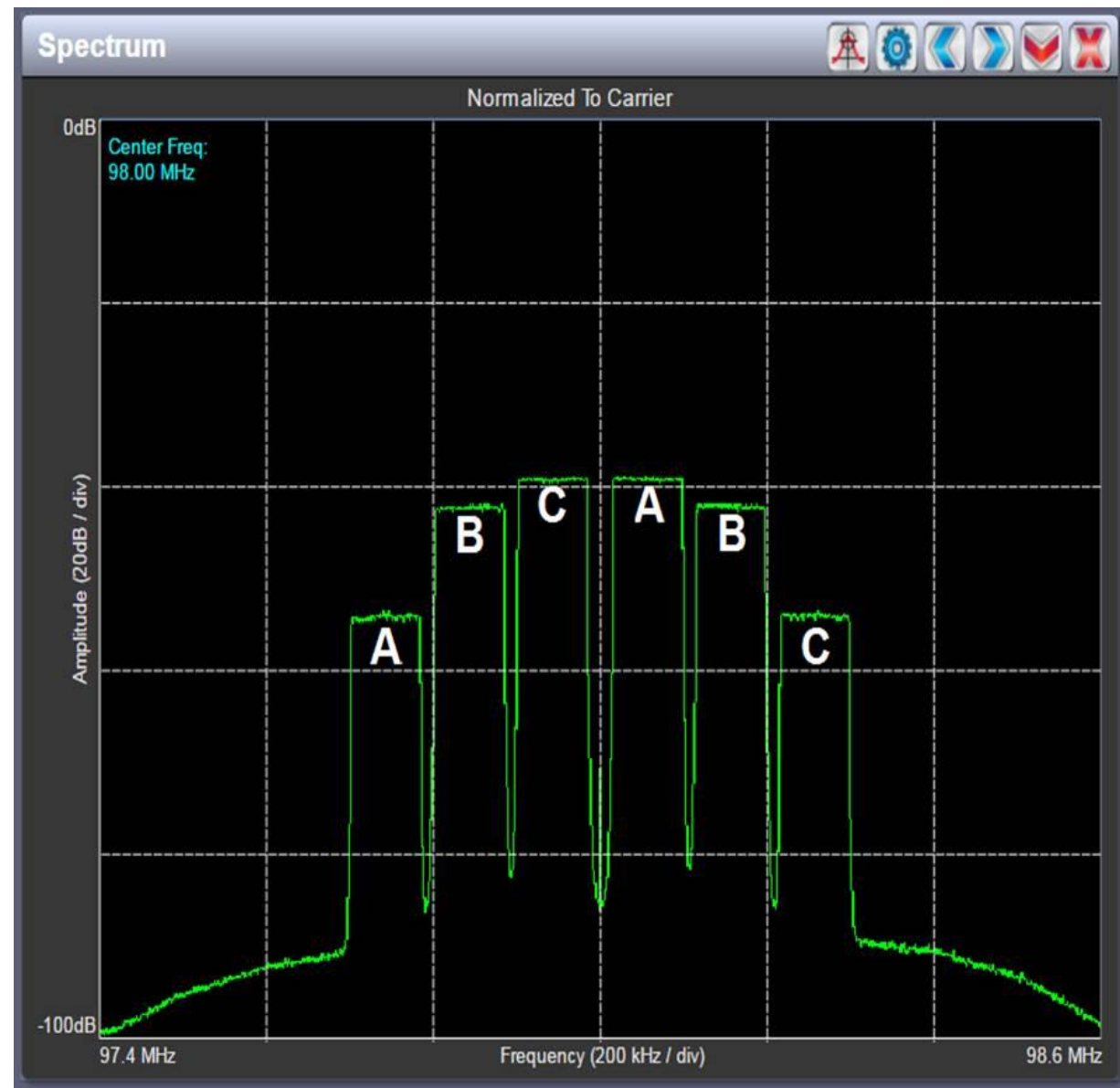
Smart addition: maintains peak-to-average, TX power scales

- 1 kW transmitter 1 station
- 2 kW transmitter 2 stations
- 3 kW transmitter 3 stations

Economy of Scale

Making Digital Broadcasting **Work.**

HD Multiplex: Interleaving IBOC Signals



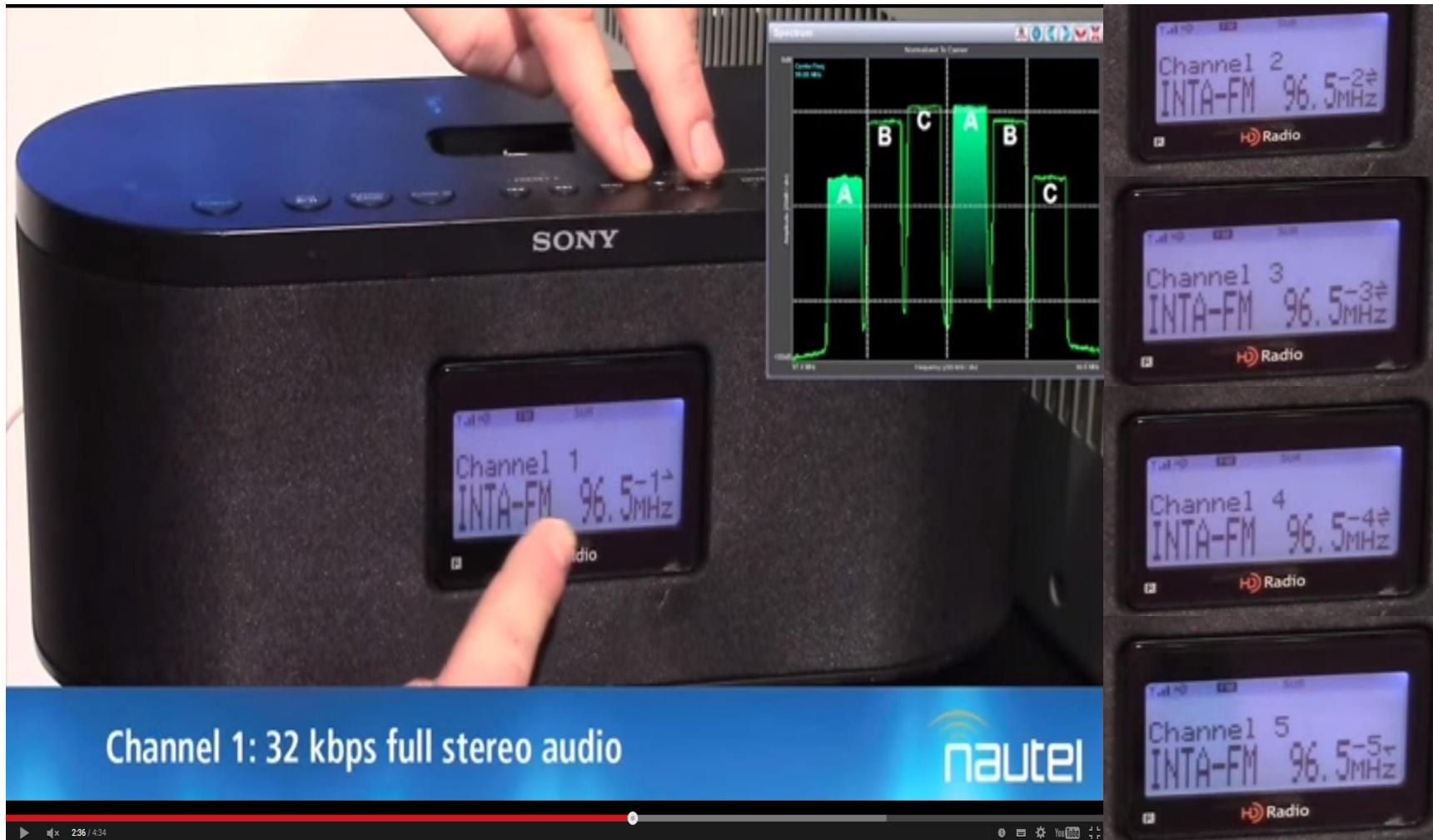
HD Multiplex: NABShow Demonstration



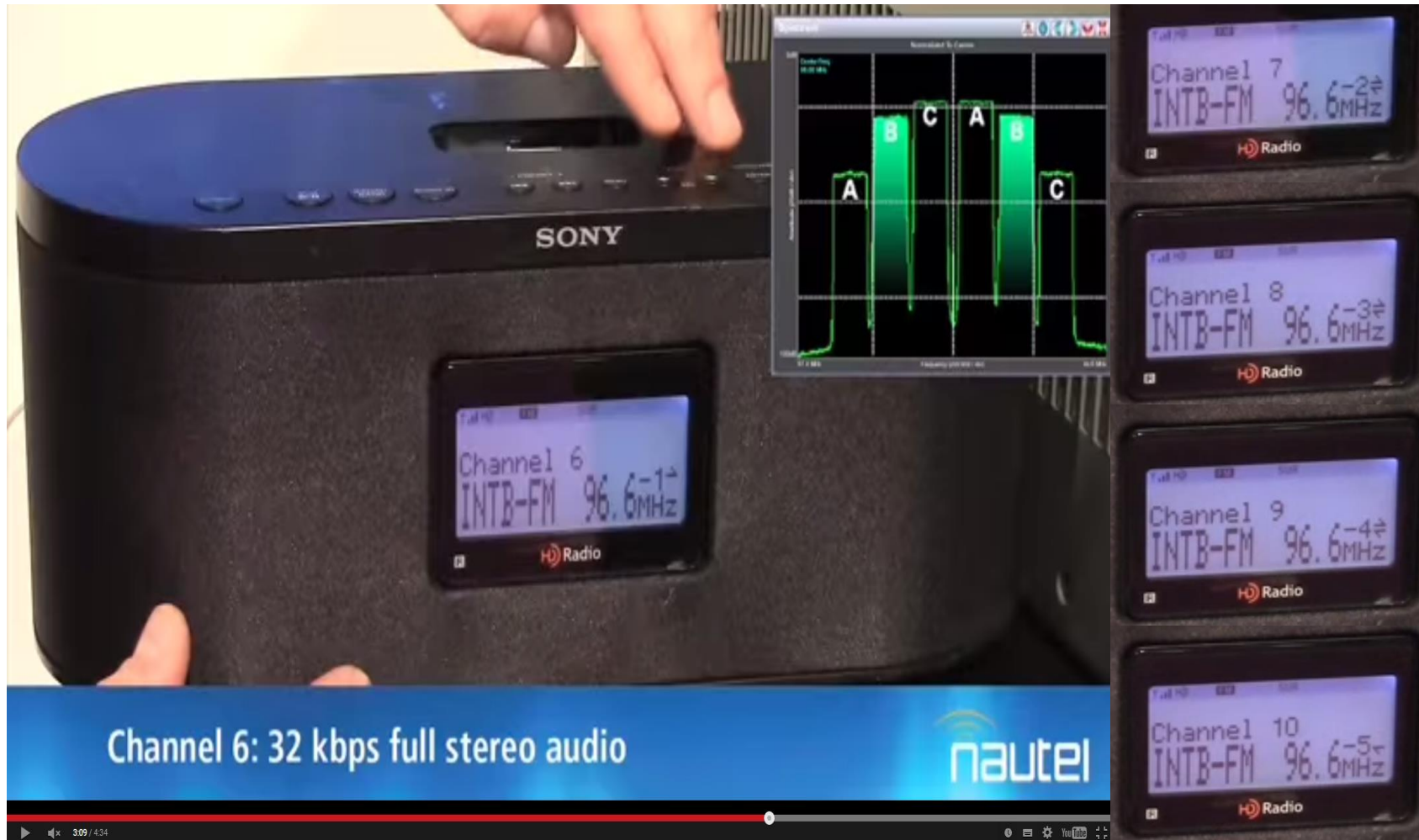
- 15 looping audio streams
 - Audio clips processed thanks to Omnia
- Running on standard transmitters
- A variety of receivers
- Watch the video at:
<http://www.nautel.com/solutions/advanced-solutions/hd-multiplex/>



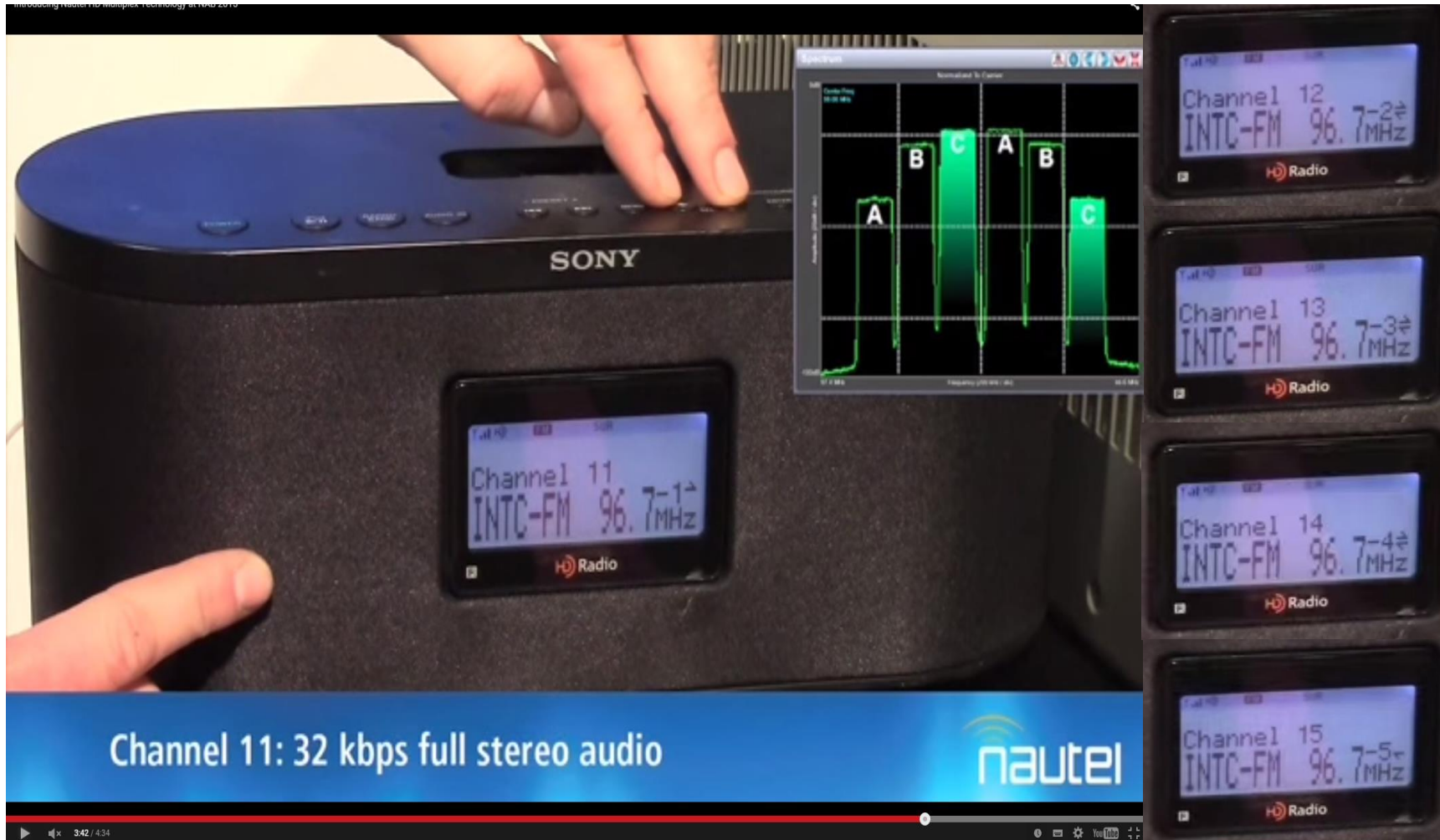
HD Multiplex Demo: 96.5 MHz Channel 1-5



HD Multiplex Demo: 96.6 MHz Channel 6-10

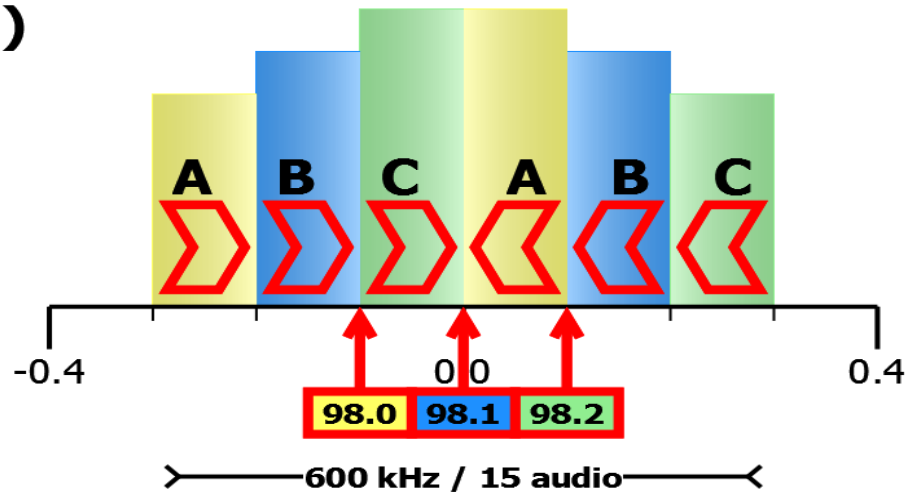


HD Multiplex Demo: 96.7 MHz Channel 11-15



HD Multiplex: Signal Configurations

a)



Reduced Transmission Energy Cost

	Analog FM	Hybrid FM+MP3	HD Multiplex MP5	MP6
RMS Power	10 kW	11.2 kW	4.2 kW	4.2 kW
AC-RF Efficiency	72%	55%	45%*	45%*
Total Power	13.9 kW	20.4 kW	9.3 kW	9.3 kW
Operating Cost	\$12,945	\$18,980	\$8,699	\$8,699
Audio Services	1	5	15	12
Per Service Power	13.9 kW	4.1 kW	620 W	775 W
Service Cost	\$12,945	\$3,796	\$580	\$725
15 Services	\$194,180	\$56,941	\$8,699	\$8,699

**95% savings in
transmission power**

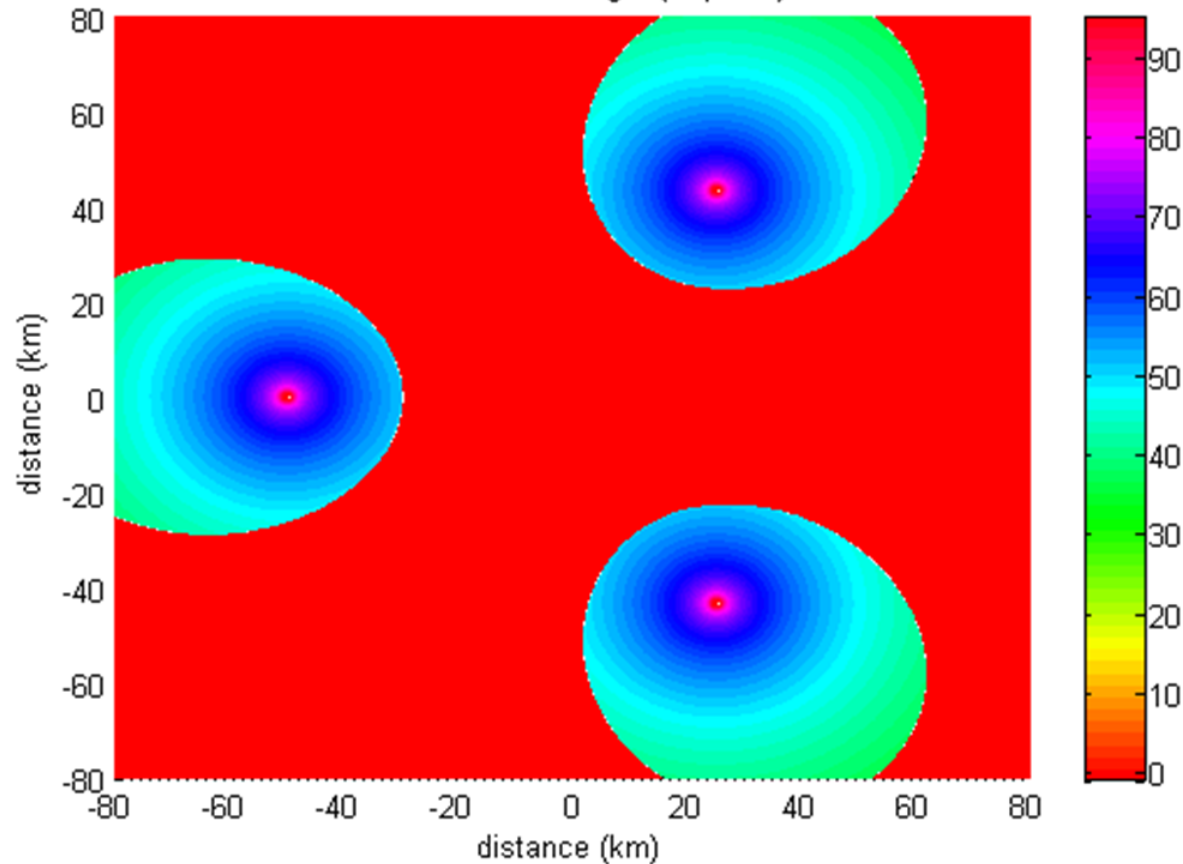
* estimated efficiency, **US10.64c/kWh

- Assumes FM coverage parity at 10% IBOC
- Single transmitter, site, and antenna system
 - Shared purpose transmission

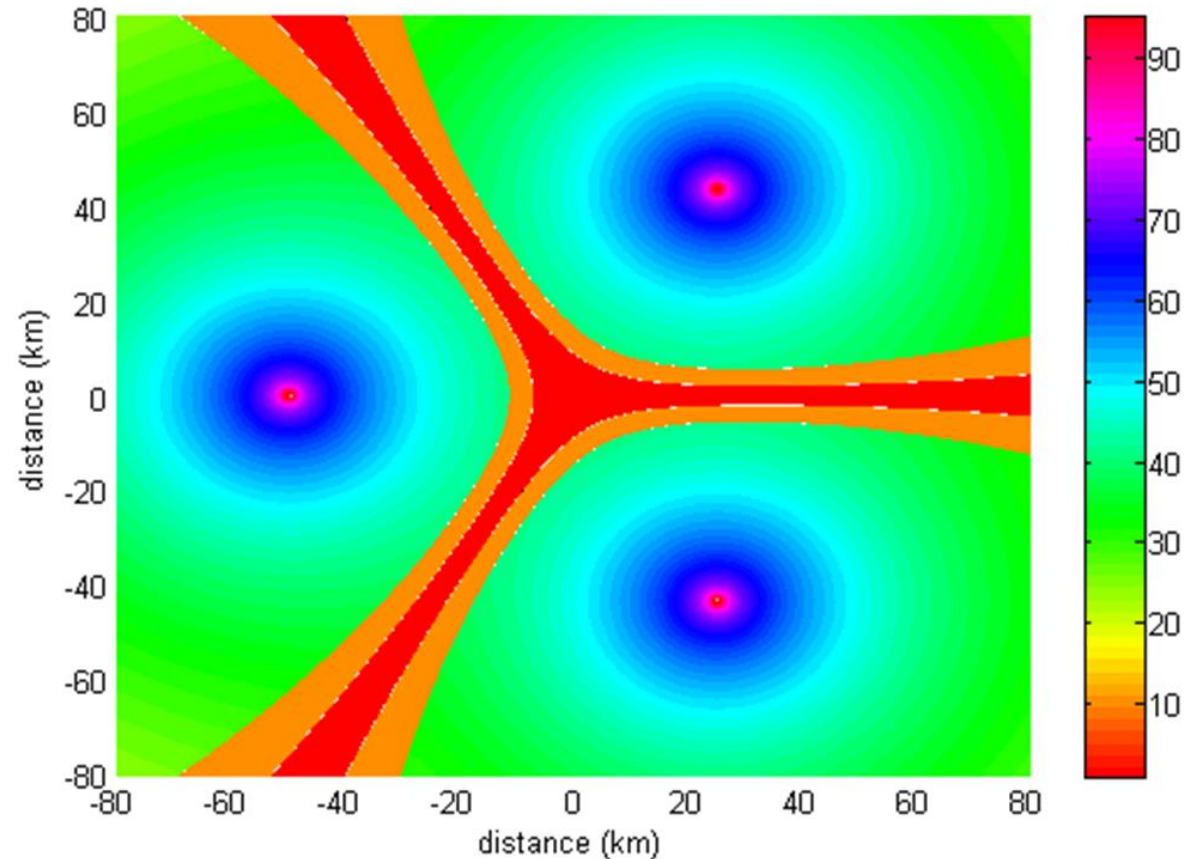


Spectral Efficiency: 2-3x Better Channel Reuse

Electric Field Strength (dB μ V/m)



FM: 20 dB co-channel protection ratio
Geographic coverage: 31.6%



IBOC: 1.5 dB (fixed), 4.5 dB (mobile)
Geographic coverage: 83% (mobile)
94% (fixed)

Spectral Efficiency: FM Band Capacity

Type	Max Audio Services	Expected audio services	Aggregate Data service Capacity
Typical FM	30	25	30 kbps (RDS)
Hybrid FM+HD	150	75	630 kbps
HD Multiplex	345	207	1.7 Mbps

same receiver base:
FM, FM+HD and HD Multiplex can all co-exist.

Protection ratios are well understood.

More audio services does **not** mean more stations

- Extending station branding to multiple services by re-using air talent
- Targeted advertising through better focused demographics on multiple services
- Increasing total reach over multiple services
- Competitive programming: make your station #1 in the market

Small broadcasters: together you are stronger

- Easy HD conversion, simulcast on HD multiplex, share the cost
- AM translators join together get multiple translators, share the cost
- LPFM – why bother with a transmitter?

HD Multiplex: Use Cases



National Broadcasters

- Offer many services, e.g. languages, kids channel, ...
- Reach everyone through single frequency networks
- Low transmission cost, existing infrastructure
- Localized content insertion

Multi-cultural programming in urban centers

- Multi-language, e.g. Hockey Night in Canada in Punjabi
- Off-the-shelf receivers: No more SCA receivers

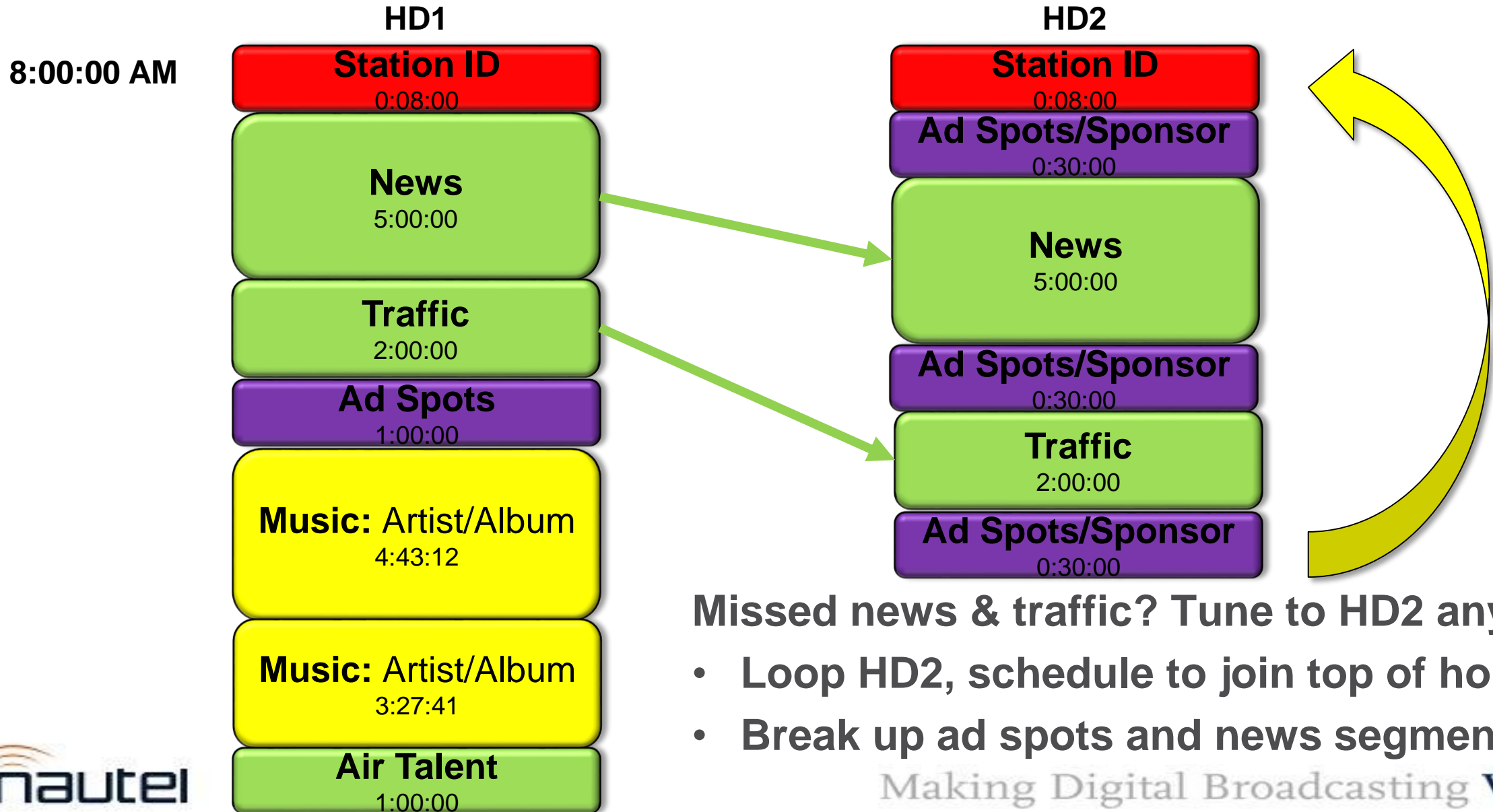
More sports play-by-play for home and away

- Multiple franchises: football, hockey, basketball, ...
- Flexible audio service assignment to match game schedules

Rural Music Diversity

- Low transmission cost
- available frequencies
- share air talent

“On-Demand” News, Weather & Traffic



Application: Coupon Radio

INSIGNIA

FM (ST) 06:29 PM AF (X) 98.3
HD1+



HD Radio®

MENU

SEEK▲

B

CH▲

PS▲

MENU

SEEK

B

CH

PS

SEL

SEEK▼

DISP

CH▼

PS▼

SEL

SEEK▼

DISP

CH▼

PS▼

- Transmit store discount coupons via QR codes
 - Added station revenue, retain listeners
 - Capture with audio tagging button, easy transfer to smartphone app
- Embed market information: call sign, timestamp

Surround Sound on HD Radio

Surround sound already demonstrated on HD Radio at NAB 2005

- Audio processing flags in HD Radio instruct receiver to decode watermark
- Tests worked great on HD1, FM worked well with strong signal
- Rear seat problem is now fixed: Check for NAB 2016 announcements

Is there interest in surround for radio?

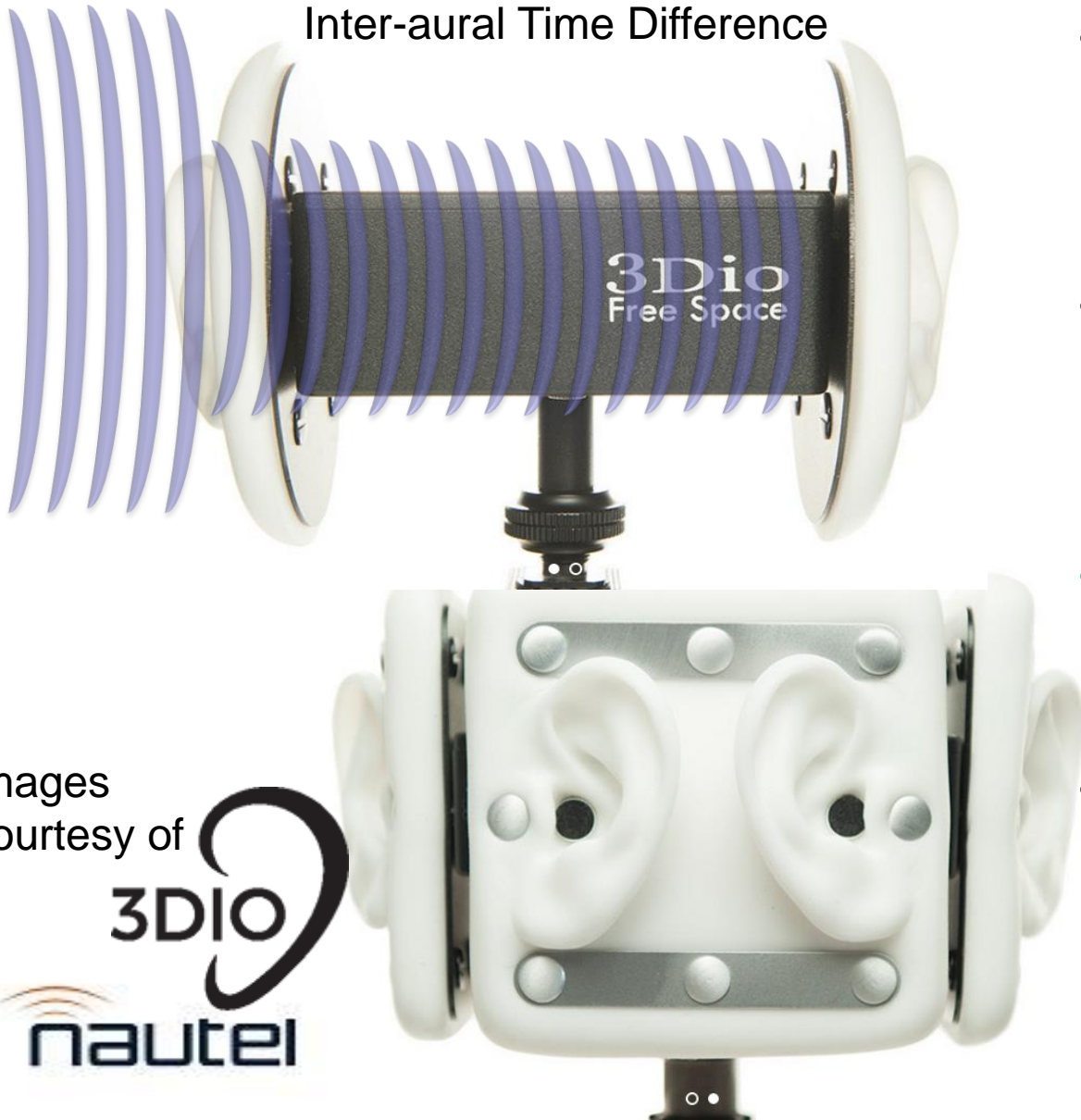
I would argue yes:

- GRAMMY “Best Surround Sound Album”
- Deliver on stage concert experience
 - Sound engineers like surround
 - keeps main clean, constrain crowd to rear
- Sportscast with crowd in bleachers experience



Binaural Audio on HD Radio

Inter-aural Time Difference



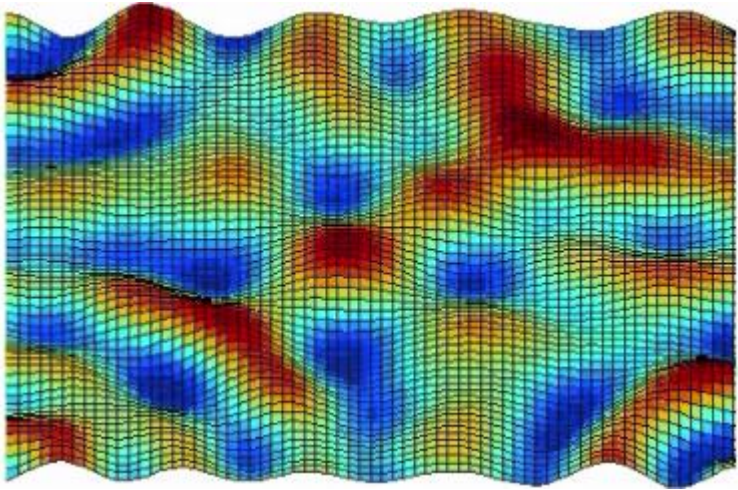
- Human head acts as filter between ears, we detect the time difference
 - Binaural recording pioneered in 1881
- New resurgence with virtual reality
 - DTS Headphone:X
 - Dolby Headphone
- HD Radio preserves binaural effect

HEADPHONES REQUIRED

- Dedicate an HD headphone channel
 - Ludicrous today
 - HD Multiplex will deliver the capacity

Making Digital Broadcasting **Work.**

Future: Immersive Audio for Radio



Immersive audio will enable true surround sound in automobiles

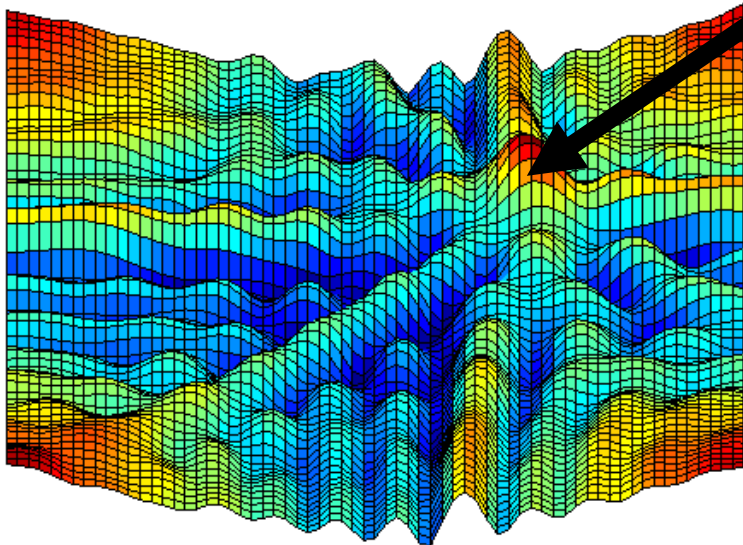
- Flexible speaker arrangements
- Entertainment system knows 3D sound scene

Soundwave beam steering

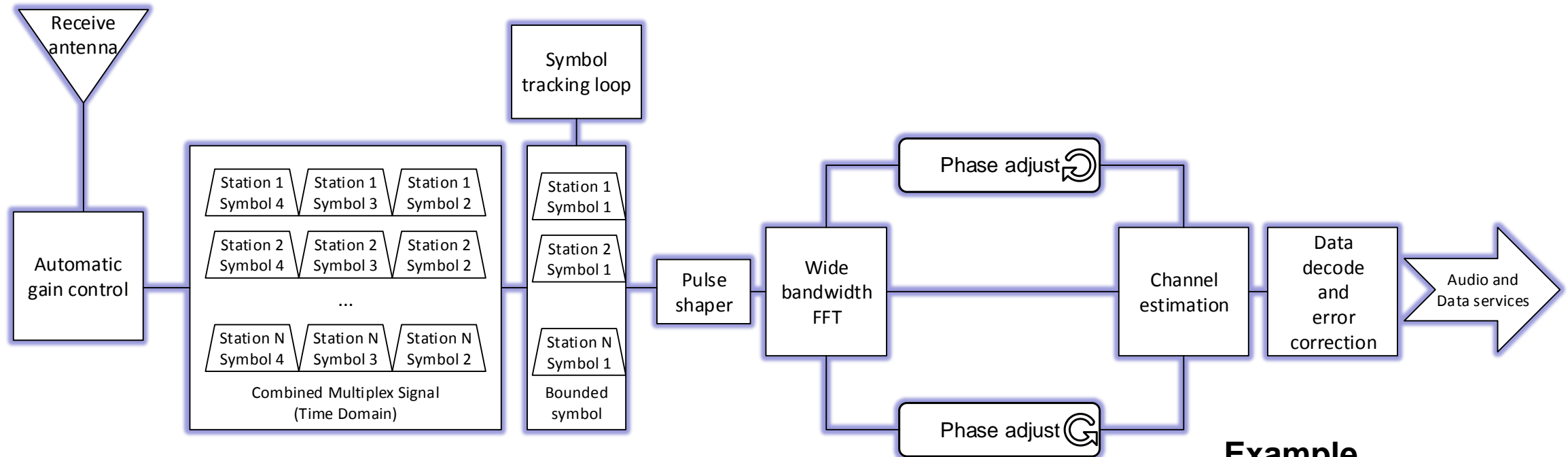
- Cancel engine noise
- Optimize for each passenger

HD Multiplex will deliver bandwidth

- 6 PCM for scene based immersive audio
- MPEG-H needs 96 kbps - 1.2 Mbps



HD Multiplex Optional Combined Receiver



All HD Multiplex symbols are synchronized

- Single symbol tracking loop
- Single FFT
- Big data pipe, but backward compatible

Example

Standard channels:

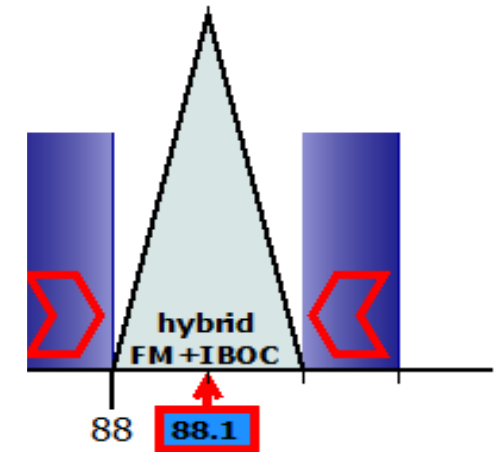
96.5 HD1

96.6 HD1

96.7 HD1

273 kbps immersive
audio channel

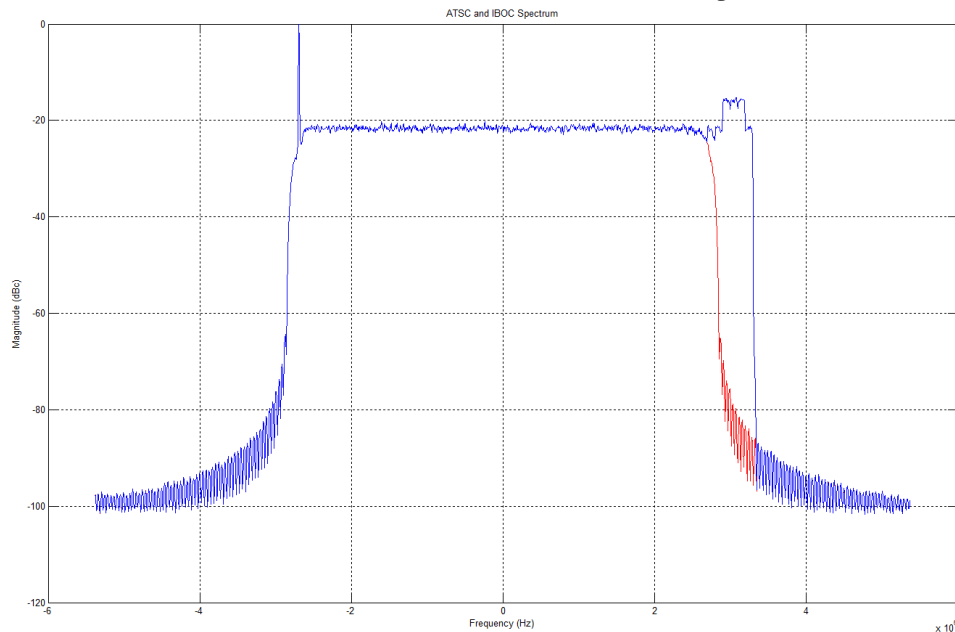
White Space: Extending the FM Band?



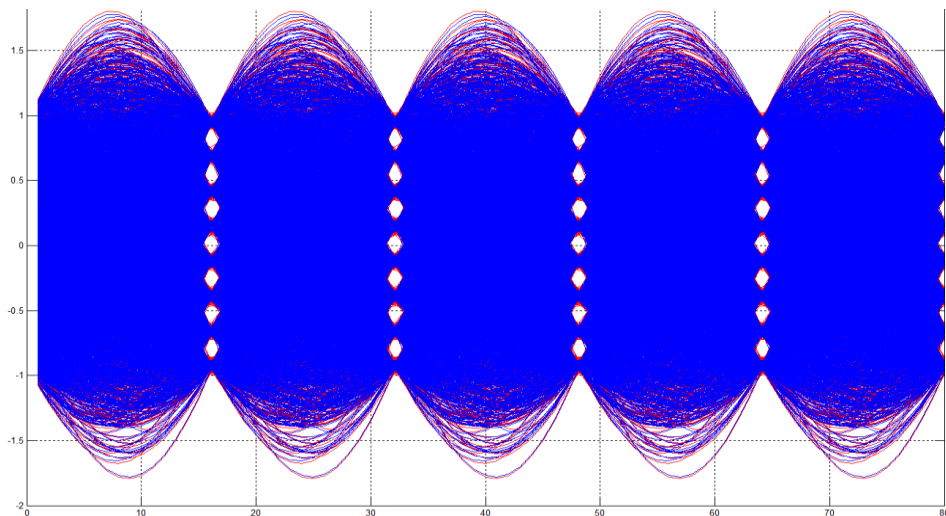
- 88.1 MHz is lowest US FM frequency
 - except KSFH-FM and K200AA-FM
- Many receivers tune down to 87.5 MHz (European tuning)
 - Fits one HD Multiplex
- We can fit 10 HD Multiplex (up to 150 audio services)
- Receivers and chipsets exist today:
 - Silicon Labs Si4777 HD Radio tuner: 64 - 108 MHz
 - NXP TEF665X HD Radio digital tuner: 65 - 108 MHz
- International interest, we'll see after spectrum auction in the US



TV6 Ancillary Supplemental Audio Service



- ATSC only uses 5.36 MHz
- 320 kHz allows for at least 2 single sideband IBOC transmissions
- Tests with FM injection at -7 dB are positive
- HD Radio will work better
 - Lower ATSC host self-interference
 - Potentially more coverage for same injection
- Combine with 88.1 MHz
 - Put full HD Multiplex centered at 88.0 MHz



Conclusion

HD Multiplex solves these problems in FM broadcasting:

1. Increase FM band capacity with better spectral efficiency
 - 10x more audio and data services
 - Single frequency network support
 - New applications including Coupon Radio and Surround Sound
2. Much lower transmission costs
 - Up to 95% lower energy
 - Shared transmitter and antenna system
 - Re-use existing FM infrastructure
3. Works today with existing receivers
 - No chicken-and-the egg problem



What are we waiting for? Let's partner to make this happen.

Thank You