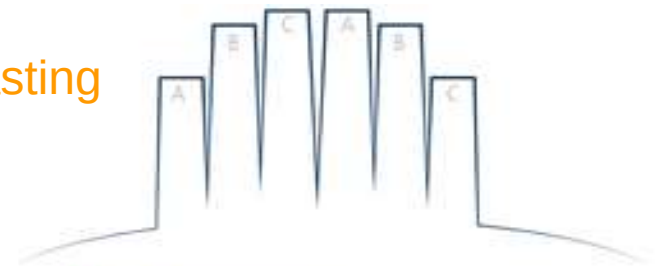


Interleaving IBOC Signals for a Digital HD Radio Multiplex

A Transition Strategy to All Digital HD Radio Broadcasting

Philipp Schmid
October 14, 2015



15 Channels in 600 kHz

9 Channels in 400 kHz

All Digital Radio

Overview

- Introduction
- Hybrid IBOC Signal Overview
- All Digital IBOC Service Modes
- HD Multiplex
- Peak-to-Average Power Reduction
- HD Multiplex Transmission Cost Savings
- All Digital Protection Ratios and Coverage Improvements
- FM Band and Extended FM Band Capacities
- AM Translators
- Conclusion

FM: What is the future for FM Radio?

FM Broadcasting is facing these challenges today:

- A changing on-demand multimedia culture
- Band II is congested in urban centers
- Lower transmission costs for national and rural broadcasters
- AM broadcasters moving to FM

Is Digital Audio Broadcasting (DAB) in band III the answer?

- Norway announced end of national FM broadcasting for 2017
- UK and Denmark are monitoring digital listening to reach 50%
- DAB Multiplex
 - Shift from single purpose to shared purpose broadcasting
 - Better spectral efficiency and transmission costs
- Can we find a FM band II solution using existing receivers?

————— **BBC National DAB Ensemble: Channel 12B at 225.648 MHZ, 1.537 MHz wide, 1.2 Mbps** —————

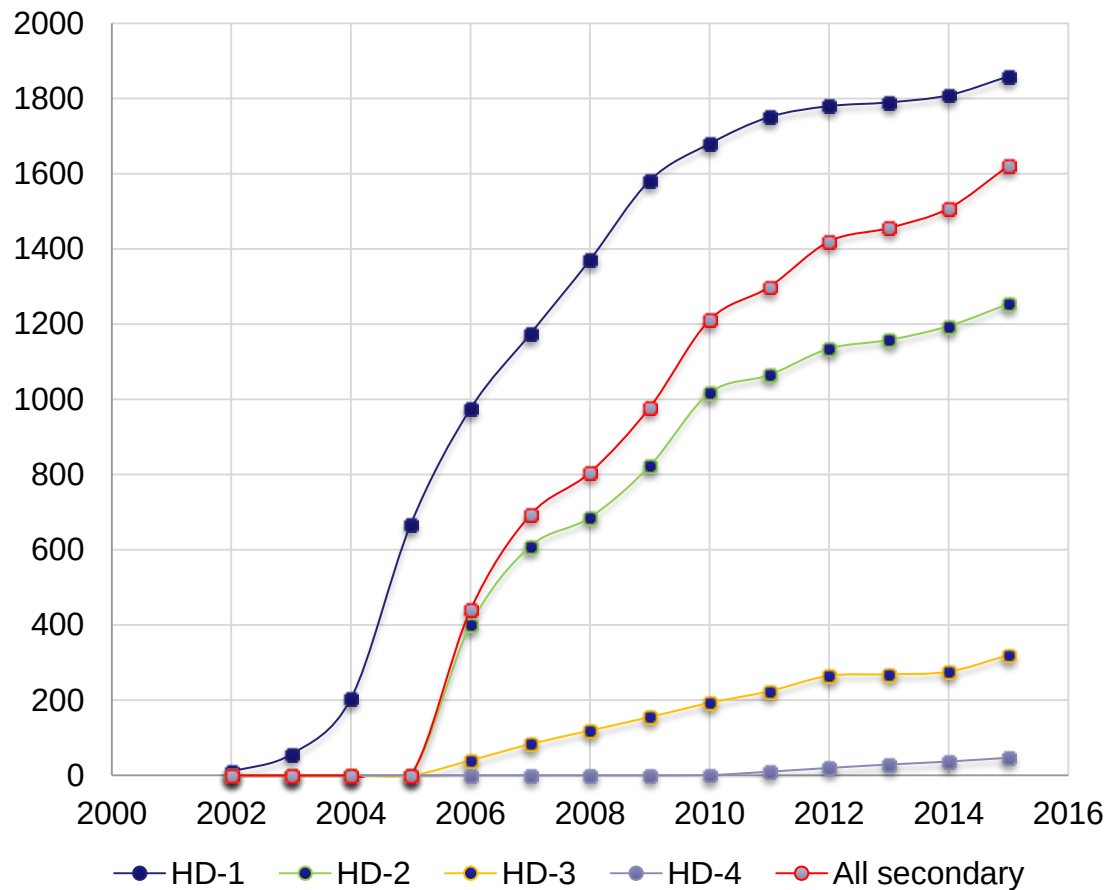
BBC Radio 1 112-118 kbps Pop Music	BBC Radio 1 Xtra 112-118 kbps Music	BBC Radio 2 112-118 kbps Pop Music	BBC Radio 3 160-192 kbps Culture	BBC Radio 4 112-118 kbps Varied Speech	BBC Radio 4 Xtra 80-128 kbps Varied Speech	BBC Radio 5 64-80 kbps News	RSLiveSportX 64 kbps Sport	BBC Radio 6 Music 112-118 kbps Rock Music	BBC World 64 kbps Varied Speech	BBC Asian 64 kbps Varied Speech	Guide 32 kbps Packets
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HD Radio: Adoption Today

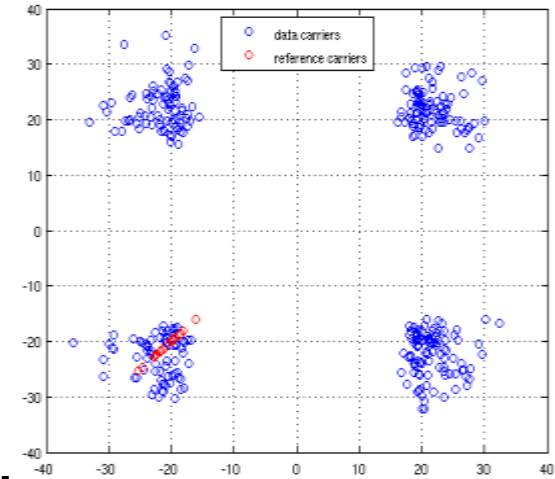
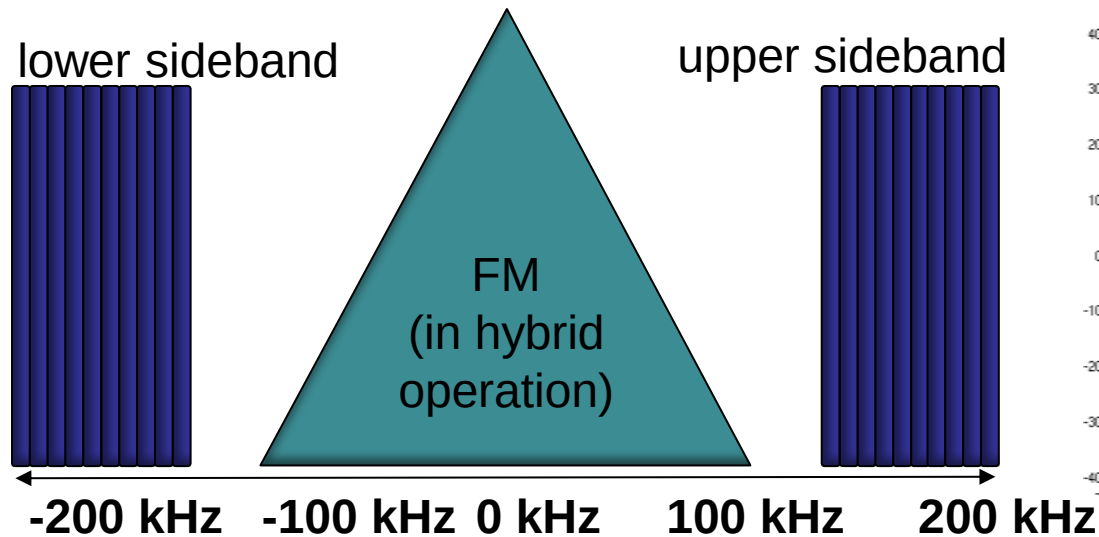
28 million receivers
2087 IBOC stations on air
3708 total HD channels
1735 multicast channels
47 stations with HD-4
International interest
increasing
10% of radio listening is
on HD Radio

Have we reached
critical mass?

FM IBOC Channels in the US

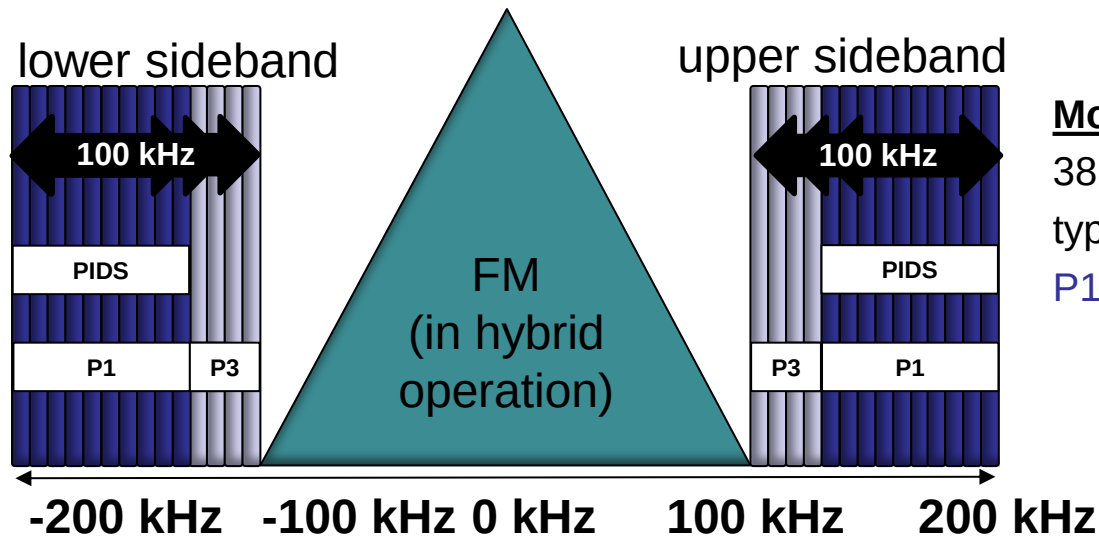


HD Radio: Hybrid IBOC Signal



- IBOC injection ratio ($P_{\text{IBOC}} / P_{\text{FM}}$)
- 10% IBOC Power $\Leftrightarrow$ FM coverage
- QPSK constellation
- 18 data carriers, 1 reference carrier

HD Radio: Hybrid IBOC Service Modes



Mode MP1

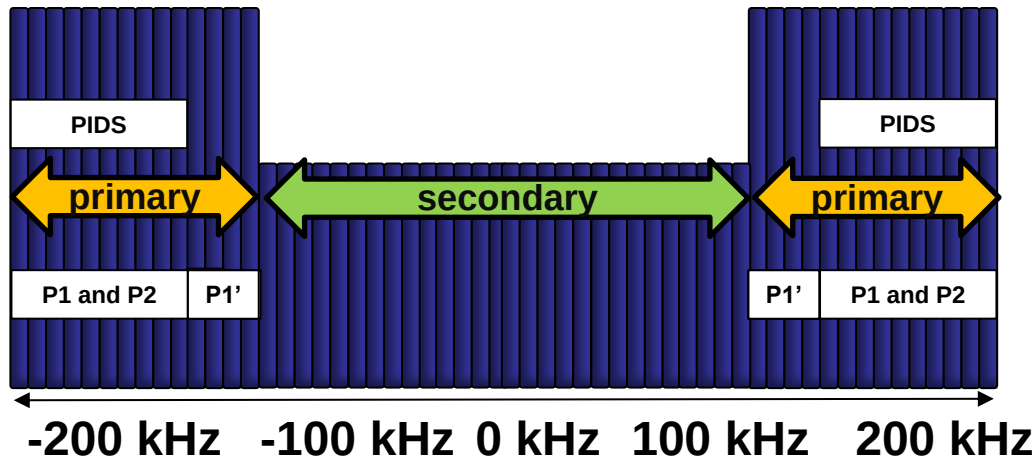
382 carriers

typical 2 audio / up to 4 audio

P1: 98.4 kbps (Robustness: 2)

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

HD Radio: All Digital IBOC Signal



Mode MP5

up to 5 audio

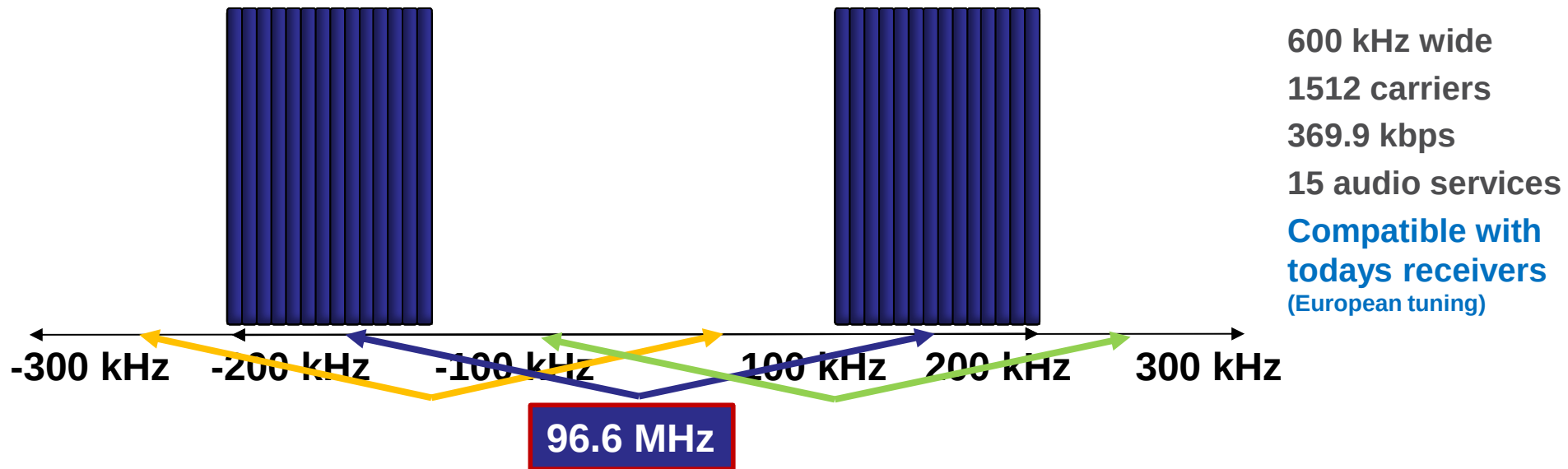
P1: 24.8 kbps (Robustness: 1)
P2: 73.6 kbps (Robustness: 2)
P3: 24.8 kbps (Robustness: 4)

+ Mode MS4

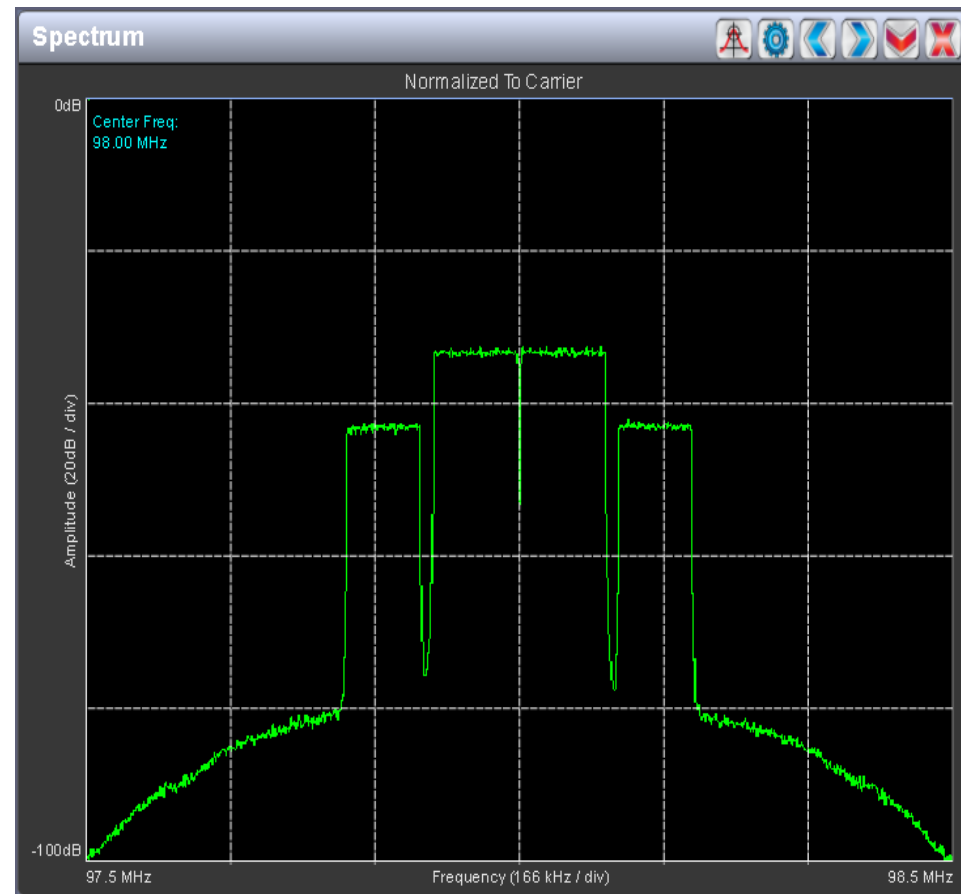
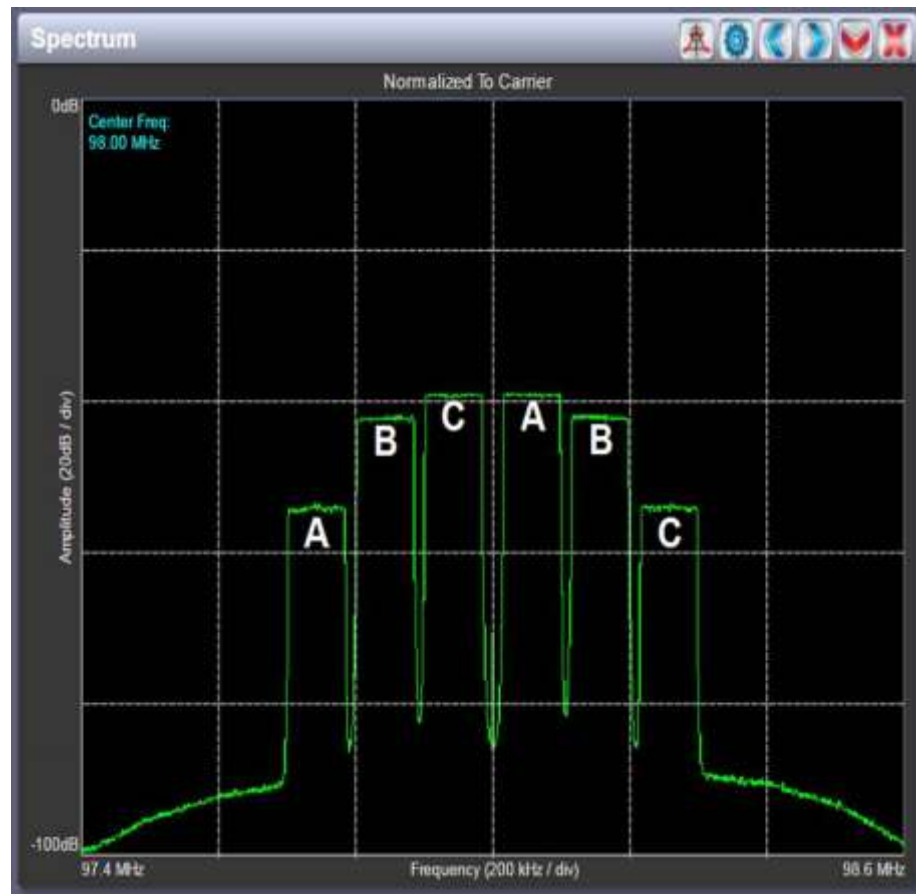
S1: 24.8 kbps (Robustness: 5)
S2: 98.4 kbps (Robustness: 9)
S3: 24.8 kbps (Robustness: 11)
S5: 5.5 kbps (Robustness: 6)

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

HD Multiplex: Interleaving IBOC Signals



HD Multiplex: Interleaving IBOC Signals



HD Multiplex: NABShow Demonstration



- 15 looping audio streams
 - Audio clips processed thanks to Omnia
- Running on VS and GV transmitters
- A variety of receivers
- Watch the video at:

<http://www.nautel.com/solutions/advanced-solutions/hd-multiplex/>



HD Multiplex: NABShow Demonstration



HD Multiplex: NABShow Demonstration

Introducing Nautel HD Multiplex Technology at NAB 2011

Channel 6: 32 kbps full stereo audio

nautel

Channel 7
INTB-FM 96.6MHz

Channel 8
INTB-FM 96.6MHz

Channel 9
INTB-FM 96.6MHz

Channel 10
INTB-FM 96.6MHz

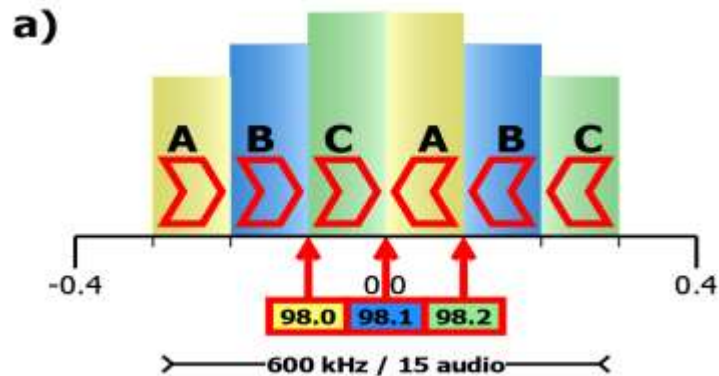


Making Digital Broadcasting **Work.**

HD Multiplex: NABShow Demonstration

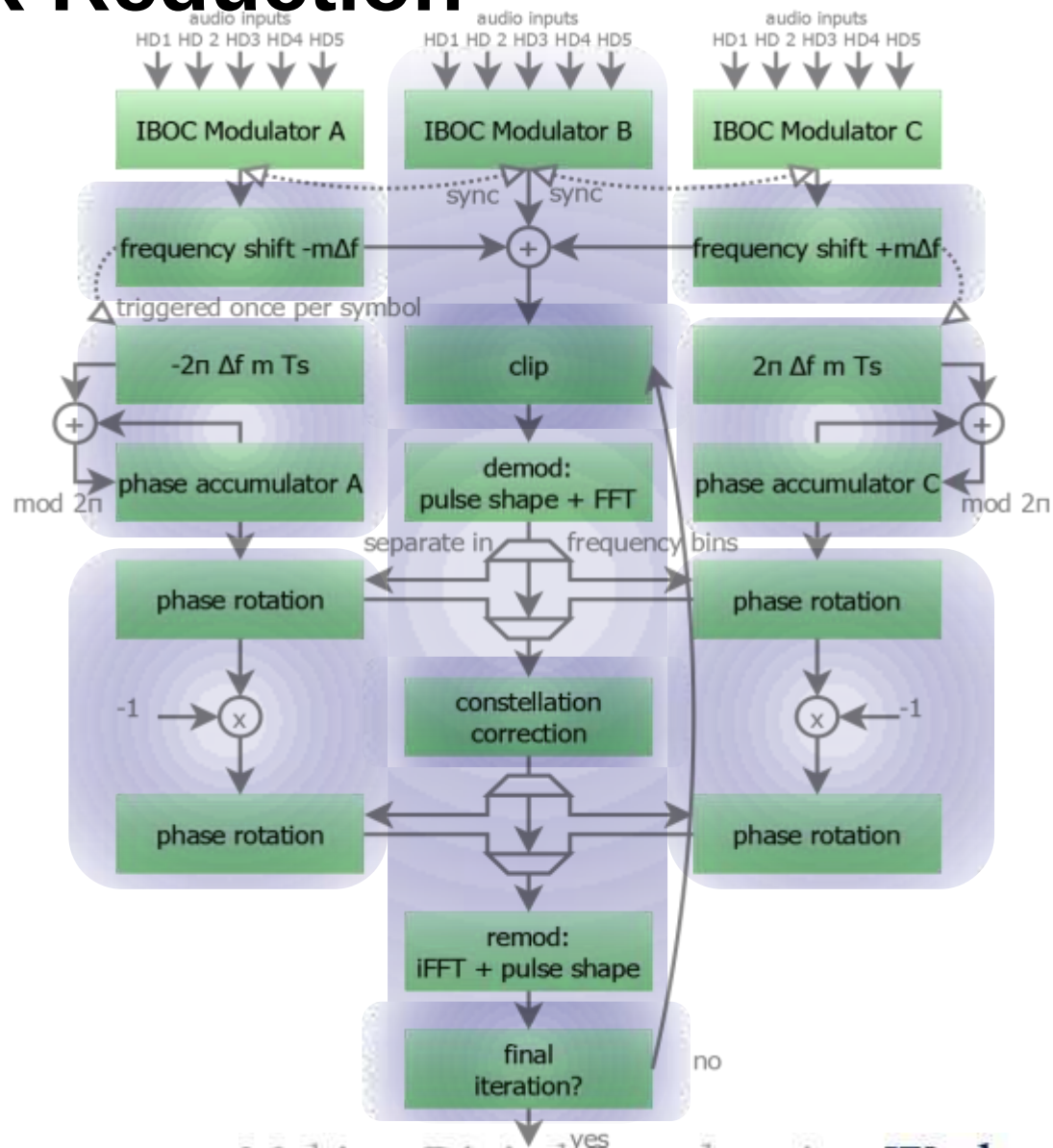


HD Multiplex: Signal Configurations



HD Multiplex: PAPR Reduction

- Standard Peak-to-Average Power Ratio (PAPR) Reduction
 - Time domain clip
 - Frequency domain correction
 - Repeat
- Frequency shift by m frequency bins
 - 100 kHz $\Rightarrow m = 275$
 - 99.928 kHz shift / 0.82 ppm @ 87.5 MHz
- 14.1° symbol-to-symbol phase shift (depending on shift)
 - Symbol-to-symbol Accumulator
 - Must be accounted in constellation



Application: Reduced Transmission 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

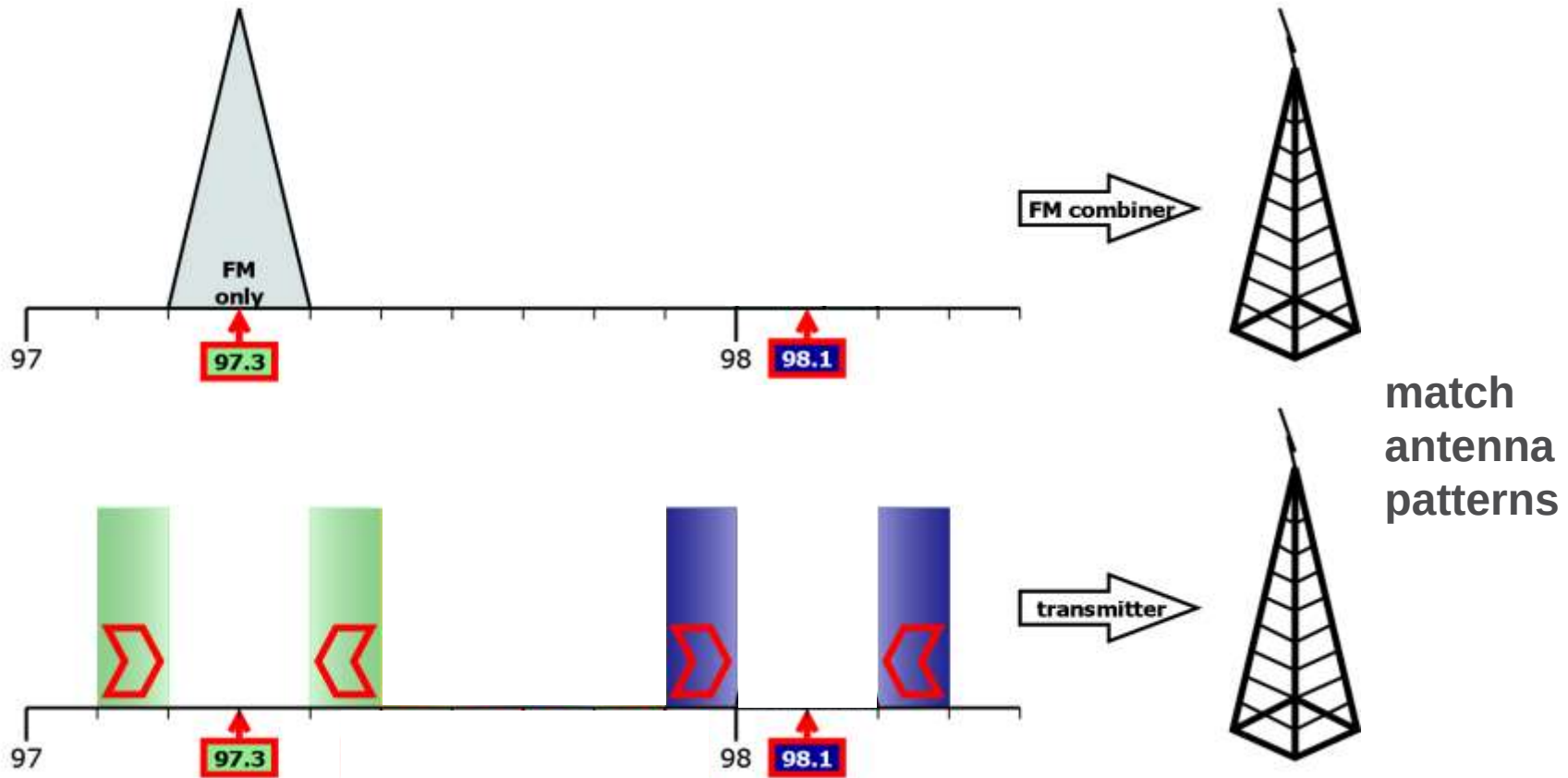
* estimated efficiency, **US10.64c/kWh

95% savings in transmission power

- Assumes FM coverage parity at 10% IBOC
- Single transmitter, site, and antenna system
- Transmitter at FM+MP3 ↔ HD Multiplex MP5
 - Nautel GV transmitter line

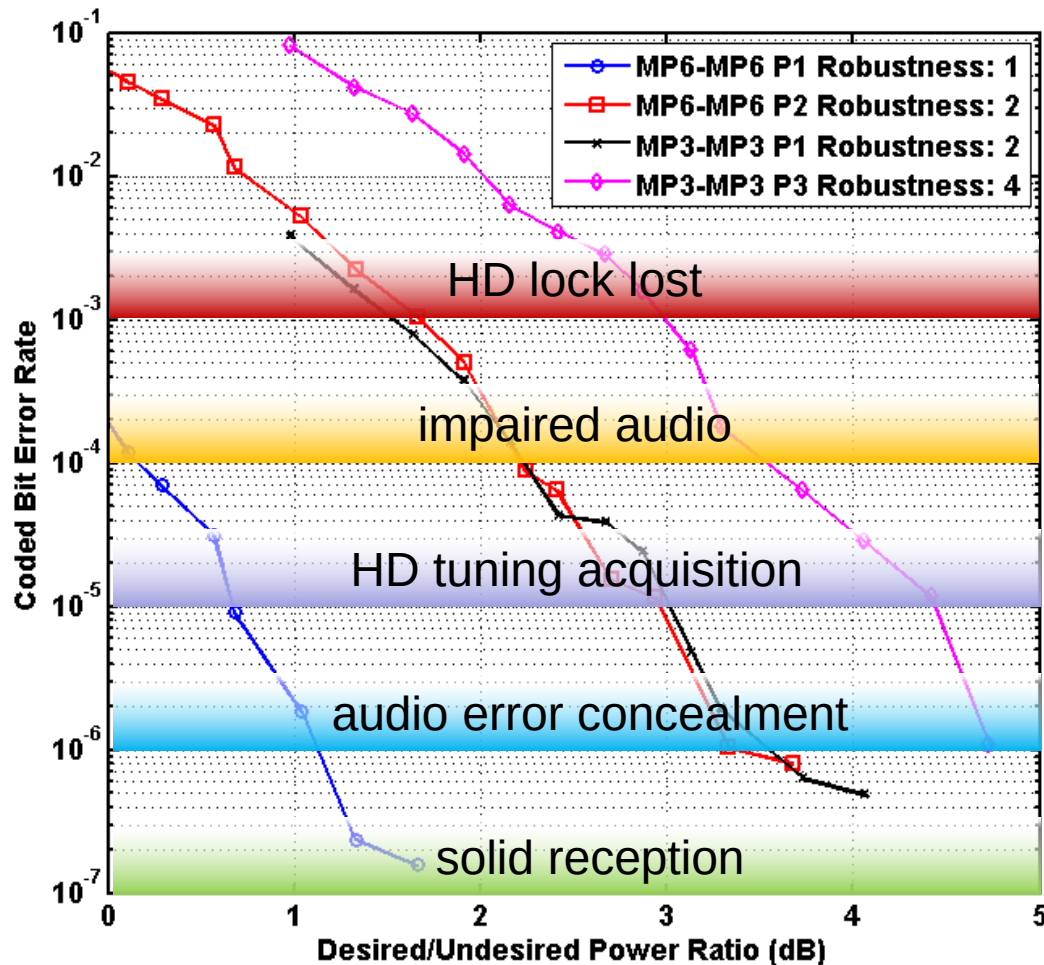


Applications: IBOC Channel Combiner



- Two 800 kHz apart FM transmitters, one IBOC transmitter
 - Maintain existing FM infrastructure
- Add additional HD multiplex carriers
- HD Multiplex can support 1 FM carrier
- High transmitter linearity required

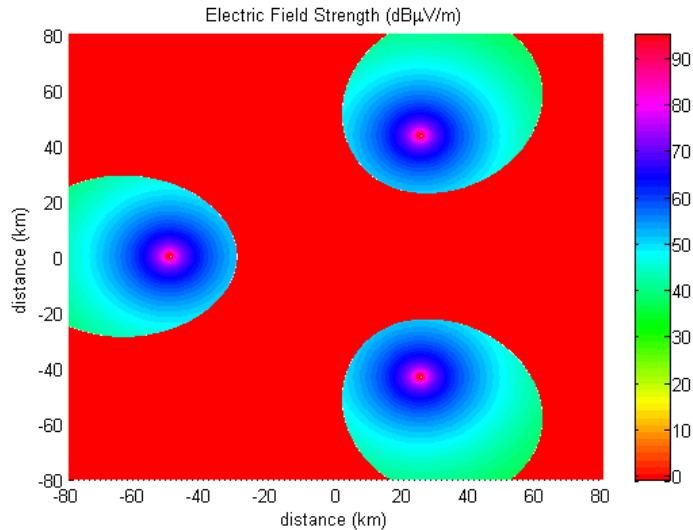
All Digital IBOC: Better Protection Ratios



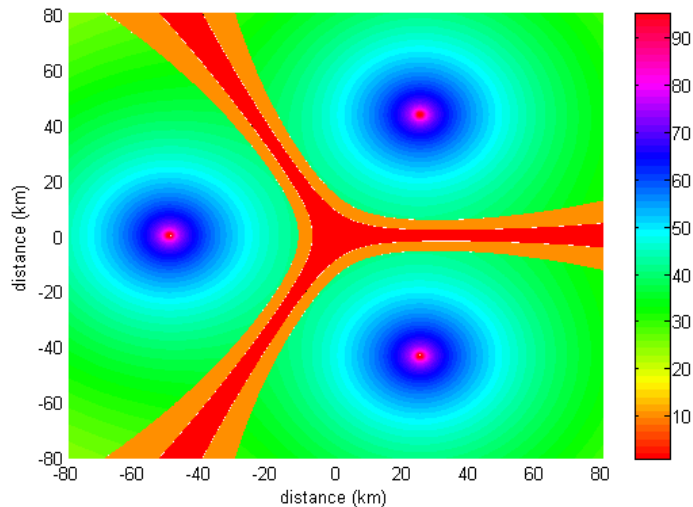
Nautel Labs coded bit error tests:

- **10^{-7} solid reception**
- **10^{-6} intermittent audio error concealment**
- **10^{-5} no receiver lock acquisition on tune in**
- **10^{-4} impaired audio**
- **10^{-3} loss of receiver lock**
- MP3 results confirm NPR Labs results of 4 dB D/U for hybrid
 - Add 3 dB for Rayleigh fading
- MP3 P3 explains why audio on P3 does not go as far
- MP6 P1 has superior performance by up to 2.5 dB

All Digital IBOC: Better Protection Ratios



FM



MP6 P1

- Okumura-Hata model (ITU P529-3)
- Short spaced transmitters
 - 6kW, 150m, 84 km apart
- 3x better band utilization
 - more IBOC stations on the dial
- Terrain variation?

Type	Robustness Level	D/U steady	D/U fading	Geographic Availability
FM		20 dB	20 dB	31.6%
MP5 P3	4	5.5 dB	8.5 dB	68.8%
MP5/6 P2	2	4.0 dB	7.0 dB	74.0%
MP5/6 P1	1	1.5 dB	4.5 dB	83.2% to 93.6%

Application: FM Band Capacity

- 4-5 times more audio services per 200 kHz
- 2-3 times better band utilization
- Up to 10 fold increase in available audio services
- More broadcast data capacity (traffic, weather, ...)
- FM, FM+IBOC, and HD Multiplex can co-exist
 - Same receiver base for all modes

Type	Max Audio Services	Expected audio services	Aggregate Data service Capacity
Typical FM	30	25	30 kbps (RDS)
Hybrid FM+IBOC	150	75	630 kbps
HD Multiplex	345	207	1.7 Mbps
Extended FM Band (76-88 MHz)	206	124	1.0 Mbps

Application: Extended FM Band

- Extend FM Band into Channel 5 and 6 (76-88MHz)
 - Japan already uses 76-90 MHz
 - Brazil is trialing FM in channel 5 and 6
 - Various proposals in the US
- HD Multiplex in extended FM band
 - Opportunity to start with a **clean slate** for frequency planning
- Only two FM stations allocated below 88.1 MHz
 - KSFH-FM 87.9 MHz Mountain View, California
 - K200AA-FM 87.9 MHz Translator Sun Valley, Nevada
- Only 9 full power TV stations on channel 6
- North American Digital Radio Band
 - “[...]according to stakeholders’ input, the radio industry would support a **North American-wide reallocation of TV channels 5 and 6 (76-88 MHz) for a new, digital-only radio band.**”

STUDY OF FUTURE DEMAND FOR RADIO SPECTRUM IN CANADA 2011-2015

Red Mobile Consulting 2012

Application: Extended FM Band Receivers

- Receiver chipsets exist today:

– Silicon Labs Si4777 HD Radio tuner:	64	- 108 MHz
– Silicon Labs Si4622 integrated data receiver:	76	- 108 MHz
– NXP TEF665X HD Radio digital tuner:	65	- 108 MHz
– ST Micro TDA7528 HD Radio tuner:	76	- 90 MHz
	87.5	- 108 MHz

- What about product support?

Example: Sparc SHD-BT1 HD Radio Receiver

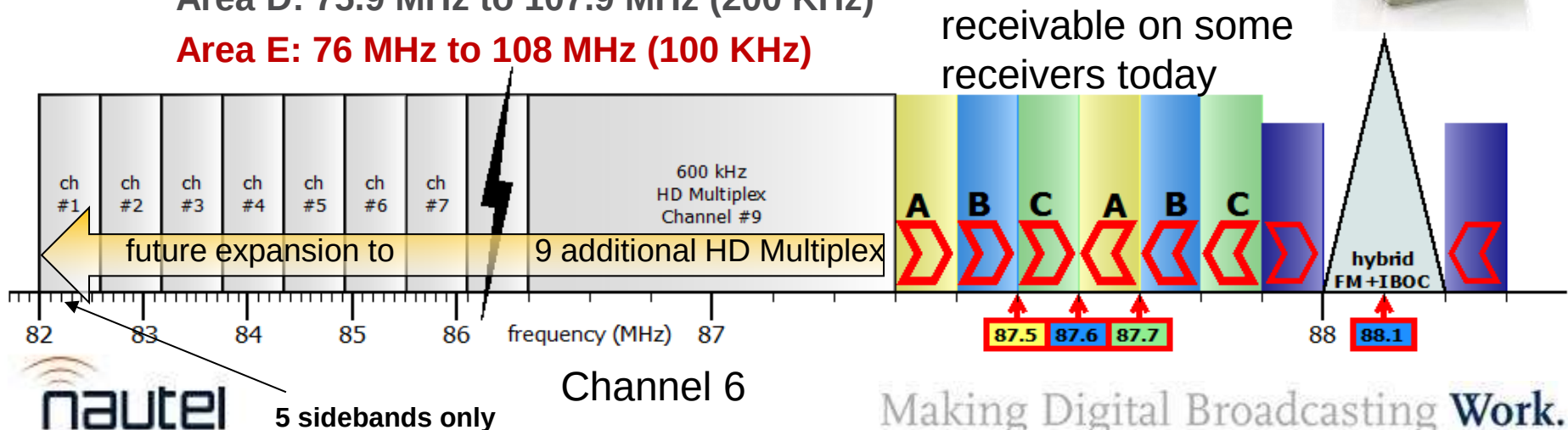
Area A: 87.5 MHz to 108 MHz (100KHz) << common

Area B: 87.5 MHz to 107.9 MHz (200 kHz, U.S.)

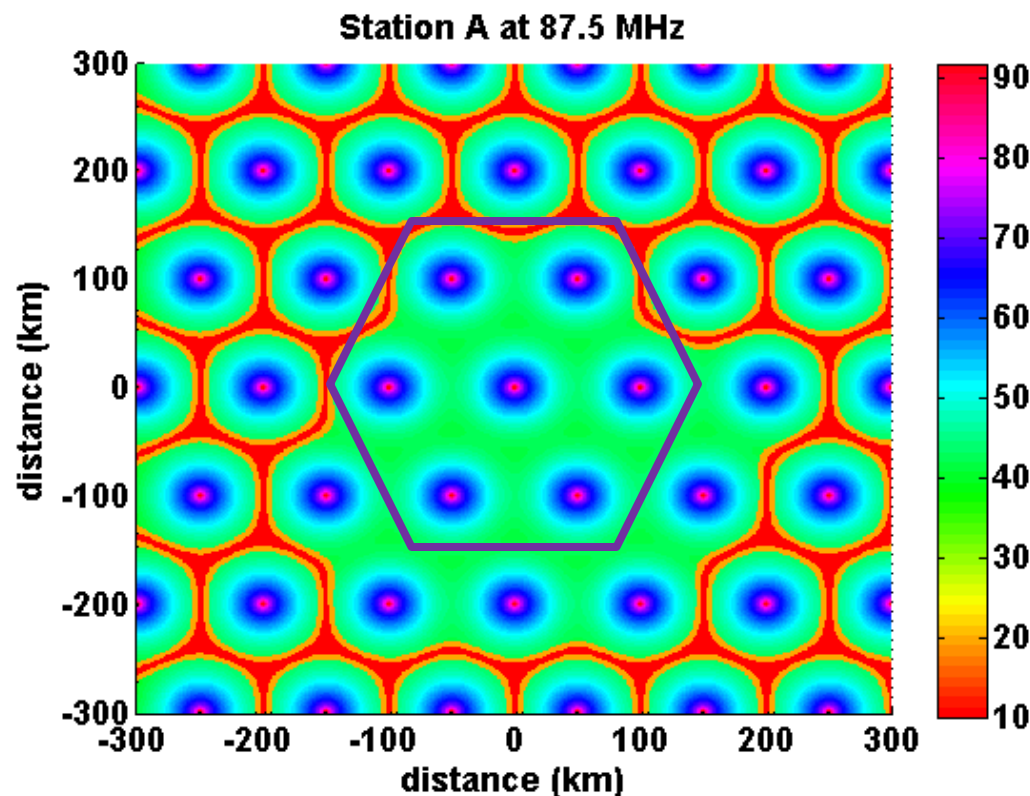
Area C: 87.5 MHz to 108 MHz (50K)

Area D: 75.9 MHz to 107.9 MHz (200 KHz)

Area E: 76 MHz to 108 MHz (100 KHz)



Application: AM Translators



“Technical limitations in the AM band have contributed to [consumer migration](#). Today, AM broadcasts provide lower fidelity than other sources of audio [...]”

Revitalization of the AM Radio Service (FCC Docket 13-249)

- **A grid of HD Multiplex TX**
 - 87.5, 87.6 and 87.7 MHz
 - 9-15 audio services
 - Keep AM carrier promote HD
- Match AM coverage through **3 independent SFNs per TX**
- FM translators could be up to 250 miles from AM station
 - Share HD Multiplex transmitters
- High fidelity audio with stereo
- FM IBOC data services
 - Station Logo, Album Art
 - Weather and traffic services
 - Sports images and stats

Conclusion

HD Multiplex addresses the stated broadcast challenges

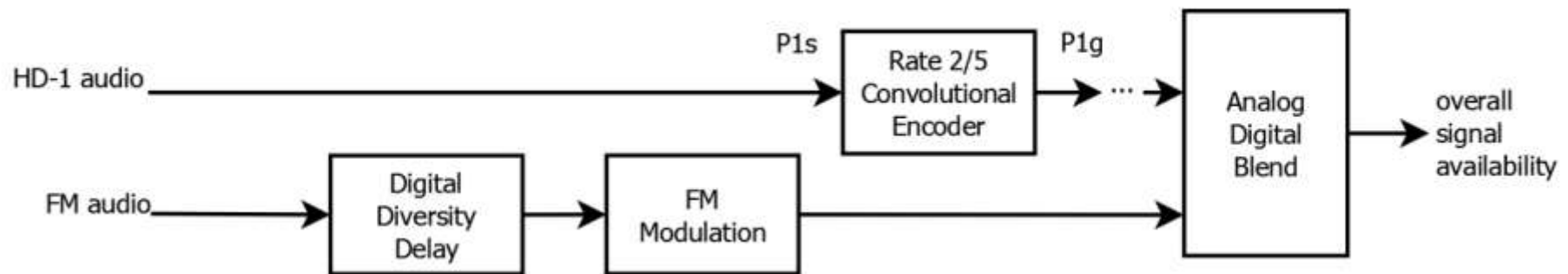
- **All digital transmission provides a richer multimedia experience with more diverse listening options**
- **Improved spectral efficiency providing more audio services in urban centers**
 - 10 fold increase in audio services
 - 124 to 200 audio services in the extended FM band
 - 2.7 Mbps broadcast data capacity
- **Lower transmission costs for national, state wide, or rural broadcasters**
 - Up to 95% transmission energy cost savings
 - Single transmitter and antenna system
 - More audio services in rural areas
- **Now is the time to plan for full digitization of the FM band and maintain its original purpose of sound broadcasting.**

Thank You



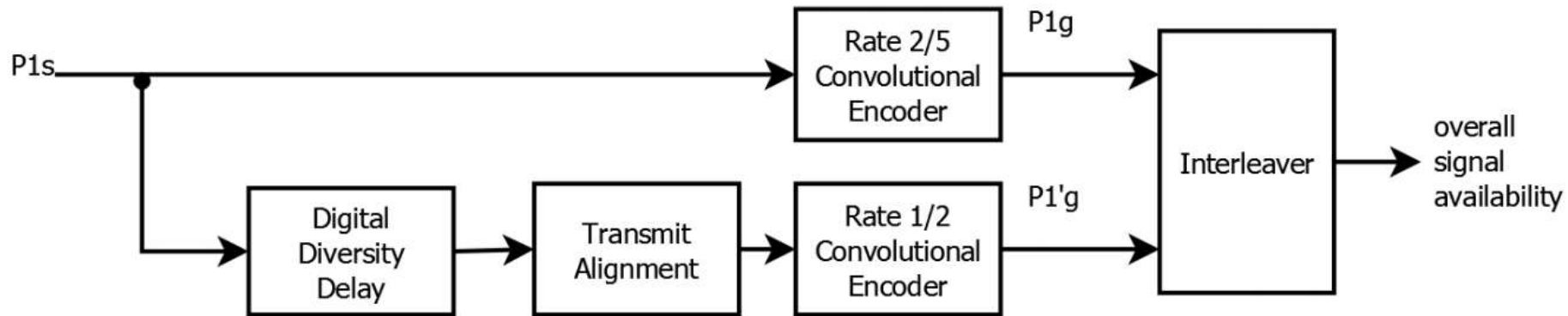
Making Digital Broadcasting **Work.**

Hybrid IBOC: Fallback Channel



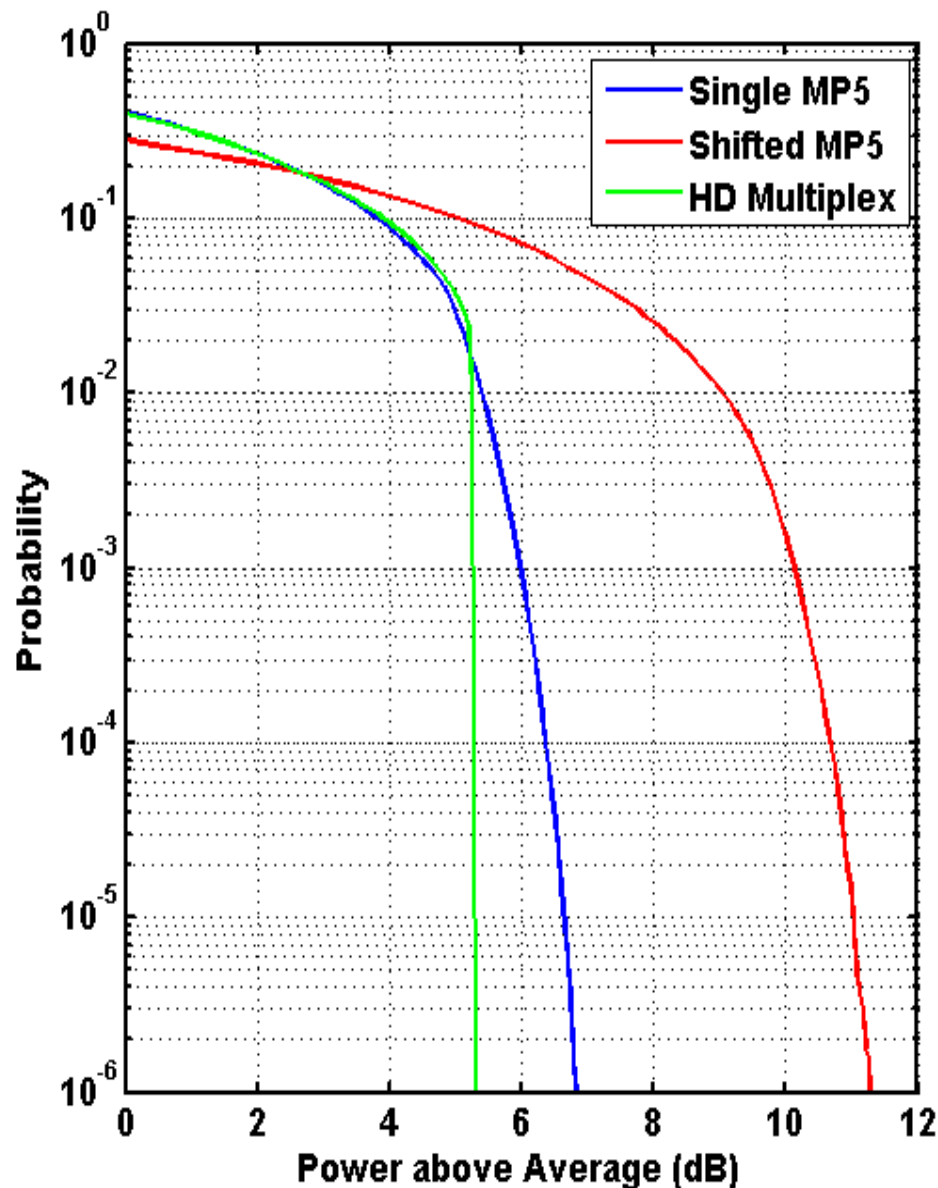
- FM and IBOC undergo different fading characteristics
- FM to IBOC **frequency diversity** improves availability
- FM to IBOC **time diversity** improves availability

All Digital IBOC: Fallback Channel



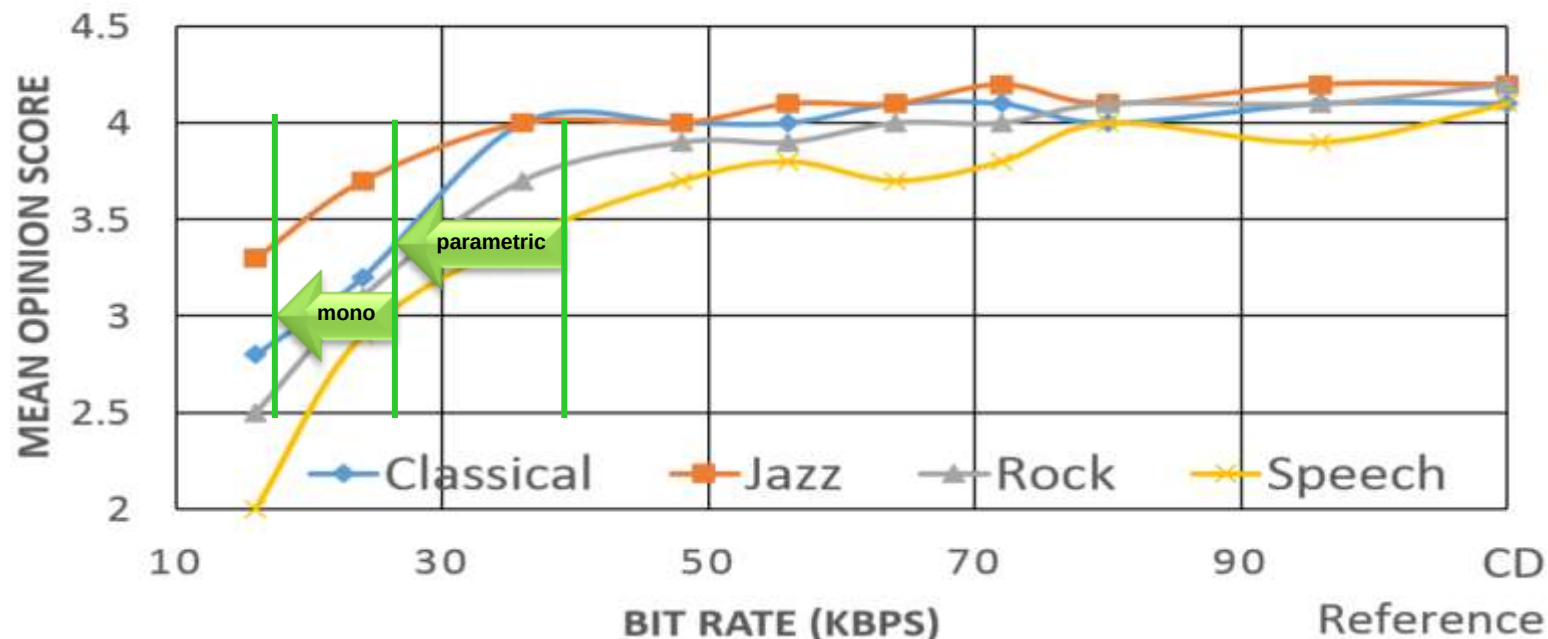
- Separately coded redundant transmission
- Placed on different carriers
- All digital service modes have **highest robustness**

HD Multiplex: Power Envelope



- Without PAPR reduction signal peaks reach up to 12 dB when adding shifted IBOC signals
 - Requires 150% more transmitter overhead compared to single MP5
- With PAPR reduction HD Multiplex achieves comparable PAPR to single MP5
 - Use a single 30 kW transmitter instead of 3 10 kW transmitters
 - Economy of scale
- Carriers of adjacent sidebands are orthogonal
 - Allows tight frequency packing
 - See paper

HD Radio: Perceptual Codec Performance



Consumer listening tests

- Most cannot tell quality improvement above 48 kbps
- Stereo mode good performance until 36 kbps
- Parametric stereo good performance until 24 kbps
- Mono mode good performance until 16 kbps
- HD audio processing and pre-conditioning is key