EXTENDING YOUR HD RADIO™ FOOTPRINT

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PURPOSE:

The purpose of this paper is to help the radio station engineer understand the facility planning requirements and technology choices to improve the HD signal coverage.

TOPICS COVERED:

- The need for increasing HD Radio sideband power
- Optimized 6dB power increase
- The RF amplifier linearity challenge
- Combining methods to reach higher HD Radio sideband levels
- Space Combining
- Common Amplification
- High power filterplexers
- Sharp tuned RF mask filters
- More HD power with hybrid crest factor reduction techniques
- Unequal HD Radio sidebands to prevent interference
- HD Radio gap filler solutions
- HD Radio Translators
- HD Radio signal quality measurement
- Summary

THE NEED FOR FULL HD RADIO COVERAGE OF THE CURRENT ANALOG FM FOOTPRINT

As HD Radio multicast services become more important to the broadcaster's business model, the need for an enhanced coverage footprint has become an imperative for reliable reception on mobile and desktop devices. The HD multicast channels do not have the protection of fall-back to analog when the edge of the digital signal coverage is reached.

On January 29, 2010, the FCC Media Bureau adopted an order to modify the FM digital audio broadcasting rules to expand digital coverage. This change to the rules will allow virtually all US FM stations to increase their HD Radio digital power by +6 dB from the current -20dBc below the FM analog power level to -14dBc. This amounts to a digital power increase of four times the current HD Radio power. The goals of increasing HD Radio power are:

- Reliable reception of multicast channels that do not have analog fall back
- Better building penetration of HD signal to portable and desktop receivers
- Better mobile HD Radio reception in suburban areas
- Better reception on portable receivers with poor antennas

OPTIMIZED +6DB HD RADIO POWER INCREASE TO -14 dBc

Most stations will want to take advantage of the full +6dB increase in digital HD Radio power. The most practical choices for increasing the HD radio power are space combining of separate analog and digital transmitters or common amplification of FM + HD through a single transmitter.

High level combining and mid level combining are too inefficient for HD Radio power increases of more than 3dB, making space combining or common amplification the only practical methods to reach the -14dBc to -10dBc levels.

SPACE COMBINING OR COMMON AMPLIFICATION?

Space combining is often the most cost effective way to increase the HD Radio power using the existing antennas and analog FM transmitter. If the new transmission system isolation and power handling requirements can be met, increasing the digital transmitter power is the only equipment change. The shortcoming of space combining is amount of mis-tracking between the analog FM and digital HD signal levels in the far field. The causes of signal level tracking error include the differences in the radiation center and the radiation patterns of the two antennas. Even systems that use a single radiator array with opposite circular polarizations for the FM and HD signals still suffer from mis-tracking at receive locations with multipath signal reflections where the two different polarizations add up differently.

As the HD Radio power level is increased, the relative tracking between the analog FM and HD Radio signals becomes more important to avoid digital into host analog interference at some receive locations. The only way to guarantee that both the FM and HD signal levels will track perfectly is to radiate them together from the same antenna with the same radiation pattern and polarization. This requires that the two signals be mixed together into the single transmission line to the antenna. The most practical way to achieve this is with a common amplification transmitter where both signals are amplified together in the proper ratio. This technique is sometimes referred to as low level combining in the exciter.

Correctly Size Transmitter Upgrade

Do I size my transmission plant for -14, -12, or -10dBc? Do I size for asymmetrical HD sidebands? Since all FM stations will be permitted to increase both of the HD Radio sideband levels by +6 dB, this should be the minimum goal for any transmitter upgrade. A good starting point is to do an analysis of your station's call letters on the National Public Radio Laboratories IBOC Power Allowance Calculator For All U.S. FM Stations located at: http://www.nprlabs.org/publications/distribution/IBOCpowercalculator/index2.php

Note that all stations, except certain, grandfathered, super power stations (check FCC web site at: http://www.fcc.gov/mb/audio/digitalFMpower.html), will be able to increase digital power by +6dB to -14dBc relative to their un-modulated FM power. In addition, to the “across the board” +6dB increase, many stations will be able to further increase the power of one or both of their HD Radio sidebands as much as 4dB more by operating with asymmetrical HD Radio sidebands, which is discussed later in this paper. The additional power required for asymmetrical sideband operation will need to be considered in selecting the proper size transmitter. It is estimated that 91% of the stations in the commercial, non-reserved, FM band segment and 82% of the stations in the non-commercial, reserved, FM band segment could increase one of the HD Radio sidebands to the -10dBc level. It is also estimated that 58% of the stations in the commercial, non-reserved, FM band segment and 50% of the stations in the non-commercial, reserved, FM band segment could increase both HD Radio sidebands to the -10dBc level.

Linearity Challenge with Higher IBOC Sidebands

- The more we increase the amplitude of the IBOC carriers, the more we must de-rate the transmitter
- At -10dBc (10%) injection, the RF inter-modulation products need to be suppressed an additional 10dB at the same time the power output is increased by 10dB this is a 20dB net improvement (100x) in linearity from that needed at -20dBc (1%) to maintain the original RF mask compliance. Due to the higher, (3-5 dB) peak to average AM component added to the constant envelope, FM signal by the higher IBOC carriers, the common amplification, FM + HD Radio transmitter must be further de-rated from Class ”C” saturated FM operation. Common amplification transmitters operating at -14dBc will typically need an additional back-off of about 1.4dB or 72% of the -20dBc rated power using standard crest factor reduction.
- As the power of the separate digital transmitter used for space combining is increased by up to +10dB, the linearity of the power amplifier will also need to improve in order to meet the existing RF Mask requirement of -74.4dBc below the unmodulated analog FM carrier. The HD-only operation has an AM modulation depth that is over 6dB, but without the linearizing effect of the constant envelope analog FM signal. The maximum available digital TPO must be reduced from what it would be at a -20dBc injection ratio in order to improve the IMD suppression required by the higher HD Radio injection level. This imposes a significant linearity challenge on the transmitter. Separate amplification transmitters will typically require additional back-off to 90% of -20dBc rated power when operated at -14dBc or 4x the current -20 dBc power.

When the IBOC sideband ratio is increased, the power output of the IBOC only transmitter is increasing at the same time that the RF inter-modulation products need to be suppressed by the same ratio to maintain original mask compliance.

To illustrate this, consider the following depictions of the RF masks at -20dBc, -14dBc and -10dBc

At -20dBc HD injection, the HD sideband to IMD ratio is ~ 35 dB as shown in Figure-1. At -14dBc HD injection, the required ratio increases to ~ 41dBc as shown in Figure-2 and at -10dBc HD injection, the required ratio further increases to ~ 45dB as shown in Figure-3. This poses a significant linearity challenge for the transmitter.

Notice that spectral re-growth limit remains the same as the HD power level increased, but the ratio of HD sideband level to out-of-band RF intermodulation distortion products continues to increase in proportion to the increase in HD power.

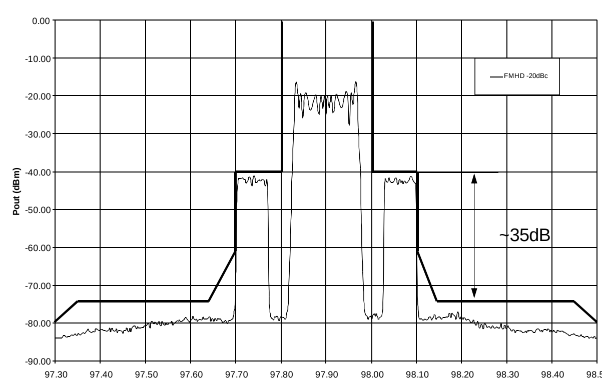

Figure-1 RF Mask for -20dBc IBOC Sidebands

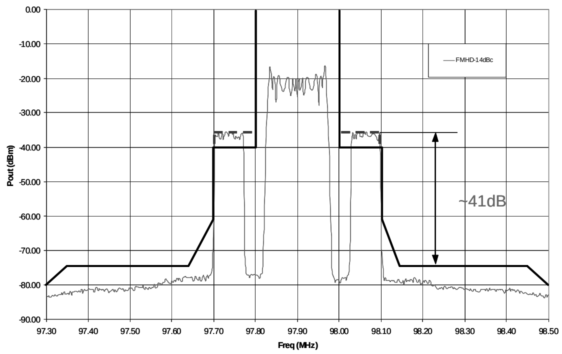

Figure-2 RF Mask for -14dBc IBOC Sidebands

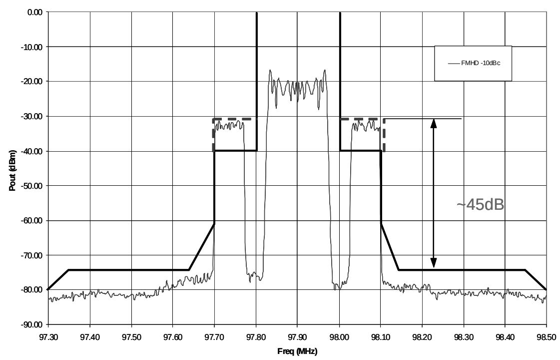

Figure-3 RF Mask for -10dBc IBOC Sidebands

UPGRADING A SPACE COMBINED SYSTEM

A 6dB increase to -14dBc requires the digital transmitter power be increased to 4 times its current power. Depending on the current digital transmitter power rating, there may be enough headroom to increase power by some number of dB now. Keep in mind that the digital only transmitter power rating will depend on the injection ratio as previously discussed.

As the digital power is increased in a space combined system, the isolation between the analog FM transmitter and the digital HD Radio transmitter feed-points to the two antennas will need to be increased. The power handling ratings of any multi-station combining system, the transmission line, and the antenna will also need to be reviewed, and possibly upgraded.

A good rule of thumb is that the isolation between the transmitters will need to be increase “dB for dB” in direct proportion to the digital transmitter power increase. The exact isolation requirement will depend on the mixing “turn-around-loss” of both the analog and digital transmitters. Transmitters with higher “turn-around-loss” will require less isolation. The limiting factor driving the isolation requirement is frequently the “turn-around-loss” of the high power analog FM transmitter.

For example, the normal isolation requirement for -20dBc operation is about 30dB. For -14dBc operation, the isolation would to be at least 36dB and for -10dBc, the isolation should be greater than 40dB. If the antenna isolation requirement cannot be met, uni-directional RF circulators may need to be added to the digital and / or analog transmitters to bring the radiated RF IMD products within RF mask limits. Figure-4 illustrates the changes in transmitter size and isolation requirements going from -20dBc to -10dBc.

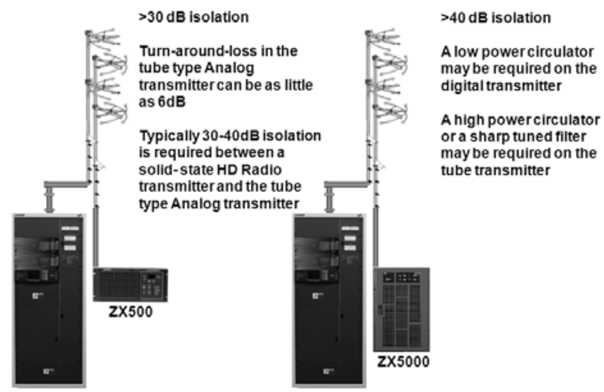

Figure-4 Separate Amplification Space Combining

UPGRADING A COMMON AMPLIFICATION SYSTEM

Increasing the HD Radio sideband levels in a hybrid, FM + HD common amplification system simply involves having the additional power output headroom in the transmitter to handle the increased peak to average ratio of the hybrid signal. The major advantage of common amplification is the ability to use an existing, single, antenna to provide identical radiation patterns and polarization for both signal components thereby providing nearly perfect signal level tracking of the FM and HD radio signals at all receive locations.

The power rating of a common amplification transmitter after increasing the HD Radio sidebands from -20dBc to -14dBc with standard crest factor reduction will be approximately (70%) of the -20dBc rating and approximately (85%) of the -20dBc rating with hybrid crest factor reduction.

In cases where the current common amplification transmitter does not have enough headroom to go to -14dBc or -10dBc, the addition of a second, identical, transmitter combined with a 3dB hybrid offers several advantages. This system provides full back-up of FM + HD Radio. Nearly full FM analog power is possible on either transmitter alone by reducing the HD sideband power level back to -20dBc. Figure-5 shows a block diagram of a typical common amplification transmitter.

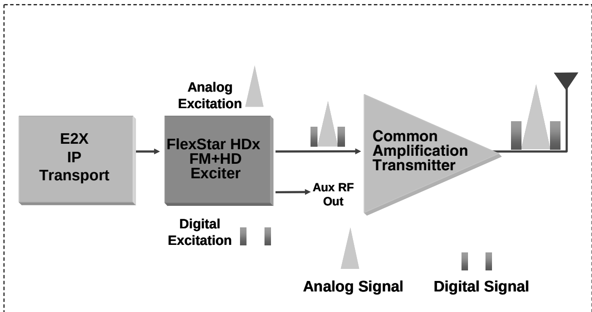

Figure-5 Common Amplification System

Harris has calculated the separate amplification and common amplification power capability of all of its transmitter models.

See Table-1 for separate amplification power ratings and Table-2 for common amplification power ratings. The transmitter ratings are shown for standard crest factor reduction. Additional power may be obtained in common amplification transmitters by using hybrid crest factor reduction discussed later in this paper.

Harris Transmitter	HD-Only IBOC Separate Amplification TPO					
	-20dBc	-18dBc	-16dBc	-14dBc	-12dBc	-10dBc
	IBOC	IBOC	IBOC	IBOC	IBOC	IBOC
ZX500	200	198	196	194	183	171
ZX1000	400	396	392	388	366	342
ZX2000	800	792	784	776	732	684
ZX2500	1000	990	980	970	915	855
ZX3500	1400	1386	1372	1358	1281	1197
ZX3750	1500	1485	1470	1455	1373	1283
Z4HD+	875	850	803	785	770	750
Z6HD+	1350	1275	1204	1178	1155	1125
ZX5000	2000	1980	1960	1940	1830	1710
Z8HD+	1750	1650	1580	1560	1410	1250
Z12HD+	2600	2550	2408	2355	2310	2250
Z16HD+	3500	3400	3210	3140	3080	3000
ZD24HD+	5200	5100	4815	4710	4620	4500
ZD32HD+	7000	6800	6420	6280	6160	6000
HT/HD+	9400	9100	8600	7800	7400	6800
HT/HD+ (Dual)	18236	17654	16684	15132	14356	13192
HPX20	8400	8100	7600	7000	6600	6100
HPX30	9400	9100	8600	7800	7400	6800
HPX40	9600	9300	8800	8000	7600	7000
HPX80 (Dual HPX40)	18624	18042	17072	15520	14744	13580

% Power with Asymmetrical HD Radio Sidebands

% of -14dBc IBOC Only Power		
% IBOC Power	HD High	HD Low
100%	-14	-14
98%	-13	-14
97%	-12	-14
96%	-11	-14
95%	-10	-14

Table-1

Harris Transmitter	FM	FM+HD Common Amplification TPO - IBOC to FM Ratio (dBc) with standard digital only crest factor reduction																	
		-20dBc			-18dBc			-16dBc			-14dBc			-12dBc			-10dBc		
		Com	FM	IBOC	Com	FM	IBOC	Com	FM	IBOC	Com	FM	IBOC	Com	FM	IBOC	Com	FM	IBOC
ZX500	**550**	413	409	4	413	406	6	380	371	9	355	341	14	293	275	17	240	218	22
ZX1000	**1100**	825	817	8	825	812	13	760	741	19	710	683	27	585	550	35	480	436	44
ZX2000	**2200**	1650	1634	16	1650	1624	26	1520	1483	37	1420	1365	55	1170	1101	69	960	873	87
ZX2500	**2750**	2063	2042	20	2063	2030	32	1900	1853	47	1775	1707	68	1463	1376	87	1200	1091	109
ZX3500	**3850**	2800	2772	28	2800	2756	44	2579	2516	63	2410	2317	93	1985	1868	118	1629	1481	148
ZX3750	**4125**	3094	3063	31	3094	3045	48	2850	2780	70	2663	2560	102	2194	2064	130	1800	1636	164
Z4HD+	**5500**	1650	1634	16	1394	1372	22	1271	1239	31	1093	1051	42	982	923	58	817	742	74
Z6HD+	**2200**	2800	2772	28	2663	2621	42	2325	2268	57	1988	1911	76	1751	1647	104	1598	1452	145
ZX5000	**5500**	4125	4084	41	4125	4061	64	3800	3707	93	3550	3414	137	2925	2751	174	2400	2182	218
Z8HD+	**5250**	4000	3960	40	3380	3327	53	3080	3005	75	2650	2548	102	2380	2239	141	1980	1800	180
Z12HD+	**7800**	6000	5941	59	5325	5242	83	4650	4536	114	3975	3822	153	3503	3295	208	3195	2905	290
Z16HD+	**10500**	8000	7921	79	7100	6989	111	6200	6048	152	5300	5096	204	4670	4393	277	4260	3873	387
ZD24HD+	**15600**	12000	11881	119	10650	10484	166	9300	9072	228	7950	7645	306	7005	6589	416	6390	5809	581
ZD32HD+	**21000**	16000	15842	158	14200	13978	222	12400	12096	304	10600	10193	408	9340	8786	554	8520	7745	775
HT/HD+	**35000**	25000	24752	248	21700	21361	339	18600	18144	456	14300	13751	550	12300	11570	730	9100	8273	827
HT/HD+ (Dual)	**67900**	48500	48020	480	42098	41441	657	36084	35200	884	27742	26676	1067	23862	22446	1416	17654	16049	1605
HPX20	**21000**	21000	20792	208	20000	19688	312	18000	17559	441	17000	16347	654	16200	15239	961	15000	13636	1364
HPX30	**31500**	28000	27723	277	25500	25102	398	21300	20778	522	19100	18366	735	17600	16555	1045	16000	14545	1455
HPX40	**42000**	31500	31188	312	28500	28055	445	24300	23705	595	22000	21155	846	19500	18343	1157	17000	15455	1545
HPX80 (Dual HPX40)	**81480**	61110	60505	605	55290	54427	863	47142	45987	1155	42680	41041	1642	37830	35585	2245	32980	29982	2998

% Power with Asymmetrical HD Radio Sidebands

% of -14dBc Hybrid Power		
% Com Power	HD High	HD Low
100%	-14	-14
97%	-13	-14
94%	-12	-14
90%	-11	-14
86%	-10	-14

Table-2

Table-2 displays the maximum HD Radio, IBOC RF power output, in watts, available from each Harris HD transmitter when operating with standard, iBiquity crest factor reduction at IBOC sideband injection levels from -20dBc through -10dBc

All power levels as measured (or interpolated) with a calorimetric power meter measuring the integrated (RMS) power of both the analog and digital RF components using standard CFR with a minimum of 3dB of headroom below the NRSC RF mask of -74.4 dBc with the FM analog carrier modulated 100% using a 1kHz monaural tone.

Note, that at -20dBc IBOC sideband injection, a transmitter rated at 10,000 watts is running 9,901 watts of analog and 99 watts of digital. This is not significant in terms of power measurement and transmitter selection for a given TPO, but at -10dBc, the transmitter rated at 10,000 watts is running 9,091 watts of analog and 909 watts digital. This DOES become significant in terms of power measurement and transmitter selection for a given TPO. The transmitter would need to be rated at 11,000 watts to achieve licensed TPO of 10,000 watts analog FM and 1000 watts of IBOC using common amplification.

HIGH POWER FILTERPLEXER COMBINING

As discussed earlier in this paper, high level combining of separate FM and digital transmitters is not practical for achieving HD Radio sideband injection levels of -14dBc or greater due to excessive combining losses.

There is one exception to this rule. A recently developed, high power, sharp tuned, filterplexer by Myat Inc. can be used to do high level combining if the analog FM transmitter has enough headroom to make up for the insertion loss of the filterplexer. The typical insertion loss for the analog FM signal is 0.83dB or ~ 21% of the analog FM power. The typical insertion loss for the digital HD Radio signal operating in MP1 mode is 1.4dB or ~ 38% of the digital power. Figure-6 is an illustration of this type of filterplexer. There may be applications where an existing, high power, FM transmitter has the required 21% headroom which would allow a moderate size digital transmitter to be combined with the existing analog transmitter for HD Radio injection levels of -14dBc or higher. When using this combining technique, the analog FM signal requires linear, time delay, digital pre-correction to compensate for the time delay distortion imprinted on the FM signal by the sharp tuned filter.

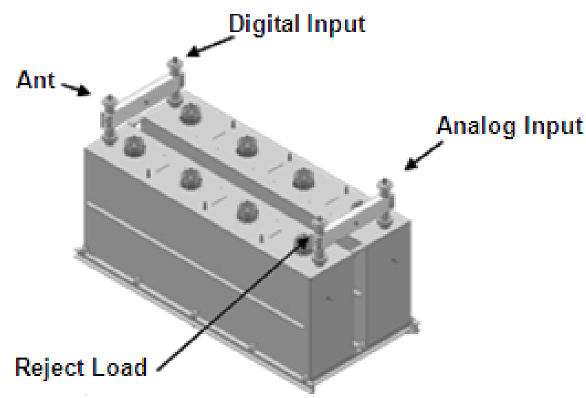

Figure-6 High Level Filterplexer FM + HD Combiner

HIGH POWER, SHARP TUNED, MASK FILTER

Another way to get additional hybrid power out of a common amplification transmitter is to allow the transmitter to go out of mask and then use an external filter that is sharp tuned around the FM+HD hybrid signal to remove the 3rd order RF intermodulation products. This technique can allow the transmitter output to exceed mask by up to 8dB and bring it back into mask compliance at the antenna feed point. ERI has developed a sharp tuned HD Radio mask filter. The FM+HD insertion loss of this type of filter is typically about 12%.

HD RADIO CREST FACTOR

The digital HD Radio signal has a high Crest Factor or Peak to Average power Ratio (PAR) compared to the constant envelope FM analog signal. This is the equivalent of AM modulation and requires linear amplification instead of the traditional, non-linear "Class-C" mode amplification used for constant envelope FM. The digital only transmitter used in a separate amplification system for space combining must have sufficient headroom to pass the relatively high PAR of this digital signal.

In order to get reasonable RF power amplifier utilization, the Peak to Average Ratio (PAR) of the HD Radio signal must be reduced by intelligent clipping techniques followed by restoration of the amplitude and phase of the reference carriers that are used to guide the receiver equalizer.

The average PAR of the combined FM + HD Radio signal is determined by a statistical process called Complementary Cumulative Distribution Function (CCDF), where the instantaneous peaks are averaged over a number of samples. Generally the average PAR determines the RMS power capability of a transmitter to meet the RF mask based on peaks that occur 0.01% of the time.

Hybrid Crest Factor Reduction

The standard Crest Factor Reduction (CFR) applied to the HD Radio, Orthogonal Frequency Division Multiplex (OFDM) signal within the Exgine modulation process does not take into account the vector summation of the HD Radio digital signal with the FM analog signal in common amplification transmission systems. Hybrid Crest Factor Reduction techniques (HCFR) can be applied to the digital signal which accounts for the vector addition when it is combined with the FM analog signal. Depending on the ratio of HD Radio sidebands combined with the FM analog signal, a 30 to 35% improvement in average transmitter power output can be obtained at a -10dBc injection level and up 16% improvement at a -14dBc injection level.

Hybrid Crest Factor Reduction only applies to common amplification systems and does not help on the digital only signal used in a separate amplification system like space combining.

Figures-7 to 9 illustrate how the PAR of the Hybrid FM+HD Radio waveform is measured.

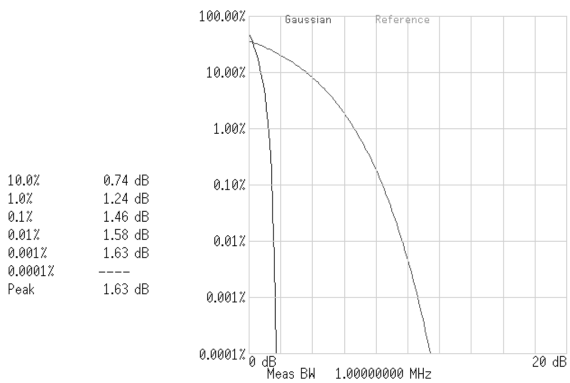

Figure-7 PAR for -20dBc OFDM pattern generator HD + FM with standard CFR

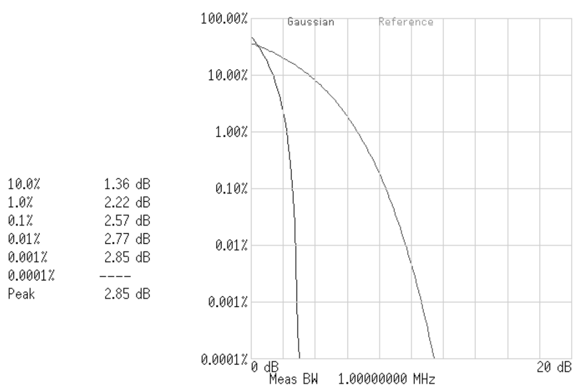

Figure-8 PAR for -14dBc OFDM pattern generator HD + FM with standard CFR

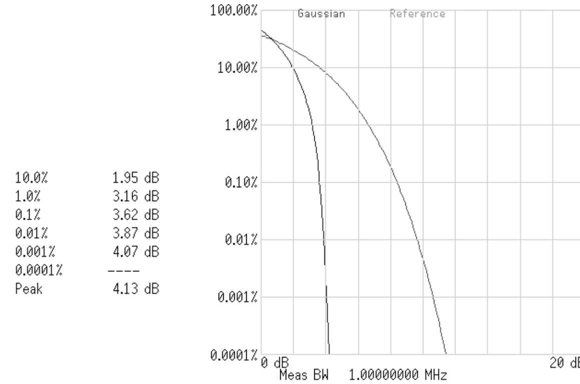

Figure-9 PAR for -10dBc OFDM pattern generator HD + FM with standard CFR

Common amplification transmission systems that amplify the HD Radio signal along with the FM analog signal must have the additional peak power capability to pass the PAR of the combined, hybrid signal. The PAR required depends on the mix ratio of HD with the FM signal and on the HD signal operating mode.

Table-3 shows the PAR of combined HD+FM signals for standard crest factor reduction (SCFR) and hybrid crest factor reduction (HCFR) at 0.01% statistical probability for various FM to HD mix ratios, and HD operating modes.

HD Operating Mode	HD Carrier Injection (dBc)	PAR (dB) @ 0.01% with SCFR	PAR (dB) @ 0.01% with HCFR	PA Utilization Improvement
MP1	-20	1.49	1.11	+9%
MP3	-20	1.65	1.22	+10%
MP1	-14	2.64	2.04	+15%
MP3	-14	2.87	2.22	+16%
MP1	-10	3.75	2.58	+31%
MP3	-10	3.96	2.72	+33%

Table-3 FlexStar HDx RF output PAR with standard CFR and HCFR for MP1 and MP3 modes

Asymmetrical HD Radio Sidebands

Unequal HD Radio sidebands can be used in both common amplification and separate amplification, space combined systems to prevent interference to adjacent channels. This will be a very important technique to maximize HD coverage for stations that cannot implement a full +10dB increase for both sidebands. Due to the redundancy of information transmitted in both the upper and lower digital sidebands, HD Radio is still receivable on standard receivers even if the upper and lower digital sidebands are unequal. Operating with asymmetrical digital sidebands can allow many stations to further increase in HD power above -14dBc on one side of the station's channel while still protecting adjacent channel stations with a closer spaced protection contour on the other side.

Power increases in only one sideband do not bring the full improvement that raising both sidebands would bring, but increasing the HD Radio power in one sideband above the other sideband will still provide some coverage improvement. The benefit to coverage will be very dependent on multipath and fading, but a +4dB increase in one sideband could provide as much benefit as if both sidebands had been increased by approximately +2dB.

The NPR Labs online IBOC Power Allowance Calculator, referred to earlier in this paper, now supports calculations for stations that are able to use asymmetrical HD Radio sidebands. It is estimated that over 90% of the stations in the commercial, non-reserved, FM band segment and over 80% of the stations in the non-commercial, reserved, FM band segment could increase one of the HD Radio sidebands to the equivalent -10dBc level. Asymmetrical sideband generation occurs within the Exgine OFDM modulation process and will be implemented with new software code from iBiquity.

Table-4 gives a summary of common amplification, FM+HD transmitter power ratings for typical asymmetrical sideband configurations. The sideband-1 and sideband-2 levels are scaled to agree with the NPR Labs IBOC Power Allowance Calculator presentation. The actual individual sideband RMS powers are 3dB less as shown in parentheses, but together they add up to the combined, RMS power shown in table-4. The PAR values are for an average between operating modes MP-1 and MP-3 with standard, iBiquity, crest factor reduction. Improvements will also be required to the digital only, CFR to accommodate asymmetrical sideband operation.

HD Sideband-1 dBc	HD Sideband-2 dBc	Combined dBc	HD Power %	Combined PAR dB	% of -14dBc Power Rating
-14.0 (-17)	-14.0 (-17)	-14.0	4.0	2.77	100
-13.0 (-16)	-14.0 (-17)	-13.5	4.5	2.90	97
-12.0 (-15)	-14.0 (-17)	-12.9	5.2	3.06	94
-11.0 (-14)	-14.0 (-17)	-12.2	6.0	3.23	90
-10.0 (-13)	-14.0 (-17)	-11.5	7.0	3.42	86

Table-4 Transmitter Power Rating Adjustment for Asymmetrical Sideband Operation with Standard CFR

ON CHANNEL GAP FILLERS AND TRANSLATORS

Single Frequency, on channel, Gap fillers and two frequency translators offer another tool to improve HD coverage without interference to others.

Both Gap fillers and translators can be HD only or hybrid FM + HD. In addition, asymmetrical sideband techniques can be used with Gap fillers and translators

Guard Interval Requirement

Digital, OFDM, signals have the advantage that perfect reception can be maintained in areas where the original digital and secondary digital signals are equal in strength provided that the differential delay between the two digital signals is maintained within the guard interval of the digital signaling system used. In the case of the HD Radio system, the guard interval is about 75uS. If the differential delay between the two HD signals is 75uS or less, reception is possible even if the two signals are equal in strength at the receiver location. The guard interval requirement must be met until the relative strengths of the two signals are more than 4dB different from each other. If there is more than 4dB difference in strength between the two digital signals, the 75uS guard interval requirement no longer needs to be met for HD radio reception. This effect is somewhat like the FM capture ratio effect for analog FM reception between two stations on the same frequency.

HD Radio gap fillers must be located with antenna patterns so that the guard interval is met in those areas where the primary and secondary (and/or tertiary) signals are all within 4dB of each other. The location of gap fillers that take advantage of terrain shielding and directional antennas can expand the area over which HD reception is possible even outside of the guard interval.

HD Only Gap Fillers

There has been much discussion about the use of digital, HD only, gap fillers in areas where there is insufficient terrain shielding to protect the primary, main, transmitter host analog FM signal from interference by the secondary FM analog signal radiated by the gap filler. Even with precise time and amplitude alignment of the main FM signal to the gap filler secondary FM signal, it is impossible to eliminate significant multipath distortions to the analog FM reception in areas where the two signals overlap and are equal in amplitude at the receiver.

For this reason, it has been suggested that gap fillers which transmit the digital HD signal only without the analog FM signal can solve this problem. Another problem is created for analog FM reception near the digital only gap filler, because the strong digital signal will be far above the normal FM to HD ratio which can cause digital to host analog FM interference. Recent tests indicate that some analog FM receivers can withstand up to +10dB of digital overdrive before the FM reception is significantly compromised. It appears that individual receiver differences will play a large role in determining how successful the deployment of digital only gap fillers can be. Harris expects to begin field tests of different HD gap filler methods in 2010.

Figure-10 illustrates an on-channel, HD Radio gap filler.

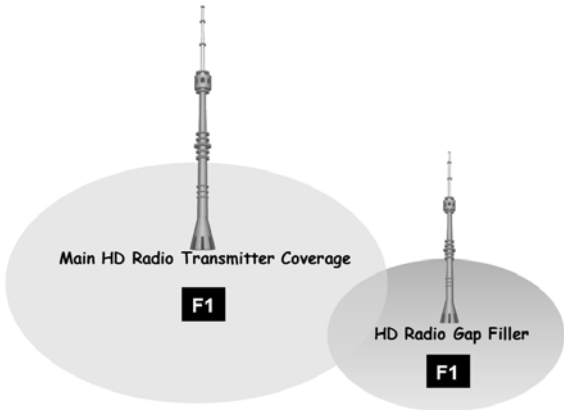

Figure-10 On-Channel HD Radio Gap Filler

THREE APPROACHES TO ON CHANNEL, SINGLE FREQUENCY NETWORK (SFN) GAP FILLERS:

- Separate, synchronous, Exgine modulation at each site with transport of E2X stream to each site (Figure-11)
- Separate, synchronous, digital up-conversion at each site with transport of high bandwidth, digital IF (Figure-12)
- Independent receive and re-transmission at each site without the need for any external data connection (Figure-13)

E2X transport stream to Exgine Modulator

Multiple Exgine modulators at each site can be GPS synchronized to provide digital HD only gap fillers. Each site will have to be time aligned via GPS or cadence in the E2X transport stream. Figure-11 shows a block diagram of the Exgine modulator type of gap filler.

Advantages:

- Host vs. gap fillers can be time aligned to maximize the guard interval protected area
  Fresh digital modulation and error correction at each site

Disadvantages:

- Cost of transporting the E2X stream to each site
- Possible licensing requirement for additional Exgine modulators at each site
- Additional transport cost to add FM analog for hybrid FM+HD output, unless host audio extraction is used
- Hardware cost

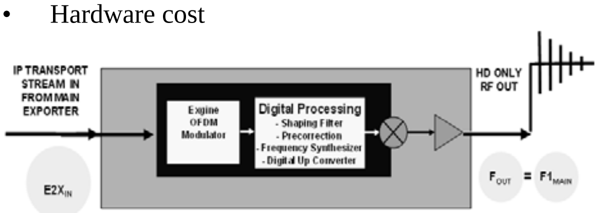

Figure-11 E2X transport stream to Exgine Modulator Gap Filler

Separate digital up-conversion from digital IF

Multiple digital up-converters at each site can be GPS synchronized to provide modulation that is an exact replica for the main, host, transmitter. Each site will have to be time aligned via GPS to the digital I/Q transport stream. Figure-12 shows a block diagram of the digital up-conversion from digital IF type of gap filler.

Advantages:

- Host and gap fillers can be time aligned to maximize the guard interval protected area
- No need to license additional Exgine modulators at each site
- Ability to provide hybrid FM+HD gap fillers in same ratio as main, host, transmitter

Disadvantages:

- Higher cost of transporting high bandwidth (~45MBpS) , digital IF signal to each gap filler site
- Additional cost of extra bandwidth for second digital IF signal to provide FM+HD ratio different than main host transmitter
- Hardware cost

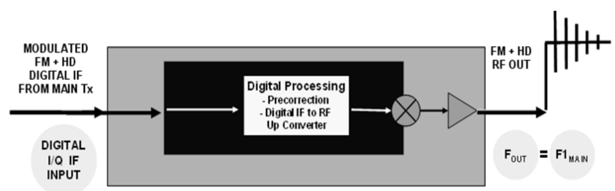

Figure- 12 Digital up-conversion from digital IF Gap Filler

On channel Receive / Re-transmit Gap Filler

This technique supports multiple, independent, sites. No transport of data from main, host, station or GPS are required. Each site will re-transmit an exact replica for the main, host, transmitter. The received signal from the main, host, FM + HD station is digitally down-converted for sophisticated digital signal processing before being up converted to the output frequency which is the same as the input frequency.

The digital signal processing provides several key functions including; echo cancellation, digital filtering, and digital precorrection to linearize the output power amplifier. The echo cancellation provides up to 30dB more isolation from the input to the output, thereby reducing the need for isolation between the input receiving antenna and the output transmitting antenna. The digital filtering can be used to change the ratio between the FM and HD Radio signals at the output. The level of the HD Radio sidebands can also be individually adjusted. Figure-13 shows the block diagram of the on channel FM + HD digital gap filler.

Advantages:
- Simplicity – only AC power required at each site
- Frequency synchronization without GPS or other external reference
- Ability to adjust ratio of FM to HD individually at each site
- Ability to do asymmetrical HD sidebands individually at each site
- Lower hardware cost

Disadvantages:
- Time alignment offset reduces guard interval protected area
- Time alignment impact on analog FM reception
- May or may not require FCC licensing

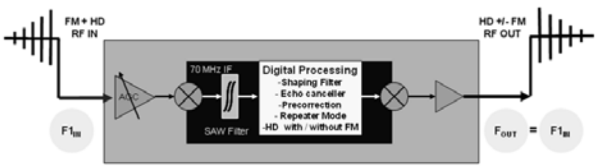

Figure-13 On channel Receive / Re-Transmit Gap Filler

HYBRID AND HD ONLY TRANSLATORS

Hybrid FM+HD and HD only translators operate in much the same way as the on channel receive / re-transmit gap filler except that the transmitted output frequency is no longer the same as the host FM station input frequency. Like the on channel gap filler, the received signal from the main, host, FM + HD station is digitally down-converted for sophisticated digital signal processing before being up converted to a different output frequency. The digital signal processing provides digital filtering, and digital precorrection to linearize the output power amplifier. The digital filtering can be used to change the ratio between the FM and HD Radio signals at the output. The individual levels of the HD radio sidebands can also be individually adjusted. Figure-14 illustrates an FM+HD Radio Translator. Figure-15 shows the block diagram of the FM + HD Radio digital Translator.

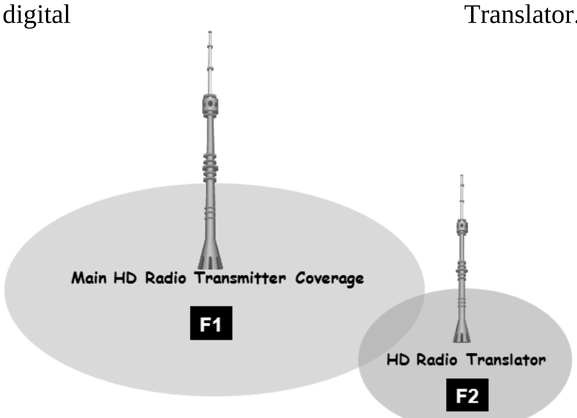

Figure-14 FM+HD Radio Translator

Advantages:
- Simplicity – only AC power required at each site
- Ability to adjust ratio of FM to HD individually at each site
- Ability to do asymmetrical HD sidebands individually at each site
- Low hardware cost

Disadvantages:
- Requires FCC licensing

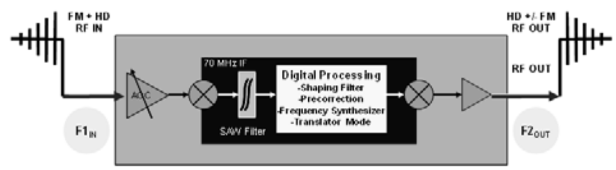

Figure-15 FM + HD Digital Translator

HD RADIO PERFORMANCE MEASUREMENT (MER)

As transmitters are driven harder and additional filtering is added to the transmission system to get to higher HD Radio sideband levels, while still remaining within the RF mask, amplitude, phase, and RF intermodulation distortions are added to the HD Radio signal. The additional distortion added by the transmission system can degrade the digital signal, thereby reducing the ability of the receiver to correct for anomalies in the path between the transmitter and the receiver.

A team of industry experts, under the auspices of the National Radio Systems Committee (NRSC), developed a method for quantifying the quality of the HD Radio signal as it leaves the transmission facility. The method utilizes a measurement of the Modulation Error Ratio (MER) as described in the iBiquity specification “Transmission Signal Quality Metrics for FM IBOC Signals” (SY_TN_2646s Rev. 01) dated September 21, 2009. This document is also referenced in the section 4.4.3 of the NRSC- G201A guidelines.

MER is a measurement of the digital signal-to-noise ratio for both the data bearing carriers and the reference carriers within the HD Radio OFDM sidebands. A measurement of MER gives the broadcast engineer a “grayscale”, diagnostic view of system problems which is more useful than the abrupt failure seen in a traditional BER measurement. The MER averaged across all reference carriers should be at least 14 dB measured at the RF output of the transmission system including any RF filters or combiners feeding the antenna system.

The ability to measure the performance of the HD Radio signal using MER, allows the station engineer to adjust the system to minimize the distortion to the transmitted signal, thereby preserving equalization/correction margin in the receiver.

MER measurement capability will be added to HD Radio exciters as well as to external HD Radio modulation monitors.

SUMMARY

- Conventional High Level Combining is not practical for more than +2dB increase in HD Radio sideband power

- Split–Level Combining is not practical for more than +4dB increase in HD Radio sideband power

- Lower Loss High Level Filterplexer Combining
  - Feasible for +10dB increase in HD Radio sideband power
  - Sharp filters cause distortion to the host analog FM signal requiring correction

- Space Combining
  - Requires up to 10x increase in HD Radio amplifier power and 10dB improvement in RF IMD suppression
  - Higher isolation >40dB and higher "turn around loss" in the transmitters are important

- Common Amplification – requires power back-off from normal common amplification power at -20dBc

- Advanced digital pre-correction and combined FM+HD, hybrid crest factor reduction (HCFR) techniques can help reduce (up to 35%) the back-off

- Common amplification with two identical transmitters combined has several advantages:
  - Full back-up of FM + HD Radio
  - Near full power possible on either transmitter at -20dBc sideband power level

- Asymmetrical sidebands will permit stations to operate with maximum HD sideband power without causing interference

- On channel HD Radio gap fillers allow spot area coverage improvements without causing adjacent channel interference

- Digital FM + HD translators offer new opportunities to serve areas now served with analog only translators

- HD Radio quality measurement (MER) will assure transmitted signal leaves enough headroom for receiver equalizer

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Monica Collins - Harris Corporation
Jeff Malec - Harris Corporation
Rich Redmond - Harris Corporation

REFERENCES:

HD Radio™ is a trademark of iBiquity Digital Corporation

iBiquity specification "Transmission Signal Quality Metrics for FM IBOC Signals" (SY_TN_2646s Rev. 01) dated September 21, 2009

National Radio Systems Committee IBOC Guidelines, NRSC-5B and NRSC-G201A

National Public Radio Laboratories IBOC Power Allowance Calculator
http://www.nprlabs.org/publications/distribution/IBOCpowercalculator/index2.php

FM Super-Powered Maximum Digital ERP Calculator
http://www.fcc.gov/mb/audio/digitalFMpower.html

"High Level IBOC Combining Using Filters" Derek J. Small, MYAT Inc. PREC 2009, April 17, 2009, Las Vegas, NV

"On-Channel repeater Implementation for HD Radio coverage improvement" Richard Redmond, Harris Corporation NAB Broadcast Engineering Conference, April 19, 2009 Las Vegas, NV

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