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First Canadian Encounter with the New Radio Transmission Technology

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ABSTRACT

The US has adopted and is deploying a digital radio technology known as HD radio, which is based on an on-channel hybrid approach called In Band On Channel or simply IBOC. HD Radio is not even on the radar of the Canadian regulators yet; however, we are already feeling the ripple effects of its implementation south of the border, in the form of a new type of interference from border town stations. HD Radio receivers are available in Canada and the number of digital radio stations has surpassed 1000.

HD Radio is an issue that can't be overlooked by the Canadian broadcasting industry and is raising myriad questions such as: Is it compatible with Canadian spectrum management rules? Will it degrade the sound quality of the FM host station? Will it degrade or reduce our coverage? Will it add interference on first and second adjacent stations? Will this added interference be manageable?

These questions cannot be addressed solely through academic exercises. Hands-on knowledge will be required to build up a realistic technical opinion. To that end, CBC Radio and CBC Technology are currently planning to launch a temporary HD radio test station that will be in operation for several months. For this trial, the most congested FM radio market in Canada was selected. Under a license from Industry Canada, CBC/Radio-Canada is preparing to implement a pilot station during the summer of 2006, at First Canadian Place in downtown Toronto.

This article will describe the IBOC technology and its potential impact on quality, coverage, interference, and reliability. It will also outline the station design variables, discuss the required compromises and choices to be made, and identify the potential impacts and benefits.

INTRODUCTION

U.S. radio broadcasters are implementing the DRB standard of "HD Radio®" on a large scale. HD Radio® is a product of Ibiquity Digital Corporation, aimed at providing an audio channel carrying an enhanced version of the FM host, plus the provision of a second audio program unrelated to the host programming.

There has been much discussion over the past few years on the implementation of HD Radio in the FM band. One of the most intriguing challenges has been determining how to combine the existing analog signal with the new digital signal without replacing the resident analog transmitter. A number of solutions have been proposed for various applications and it seems appropriate to suggest that each solution is dependent on the current condition of the transmitter site, necessitating site-specific solutions.

The most low-loss solution currently offered is to combine the analog and digital signals within the antenna. This may not be viable in all situations; if not, a minimum-loss combiner system on the ground may be employed.

Review of a Few FM Notions

Since IBOC is designed to interface with FM from a spectral standpoint, a review of a few notions of FM as we know it is appropriate

Frequency Modulation, or FM, is an analog modulation method that is characterized by the modulation method in which the modulant signal amplitude drives the frequency of the carrier. In current FM (mono) broadcasts, the signal is allowed to deviate from its center frequency up to +/- 75 kHz. This allows a practical signal-to-noise ratio of around 50 dB in the best of the coverage area.

FM Frequency Allocation

The FM band ranges from 88 MHz to 108 MHz and is divided in 100 FM allocations of 200 KHz each.

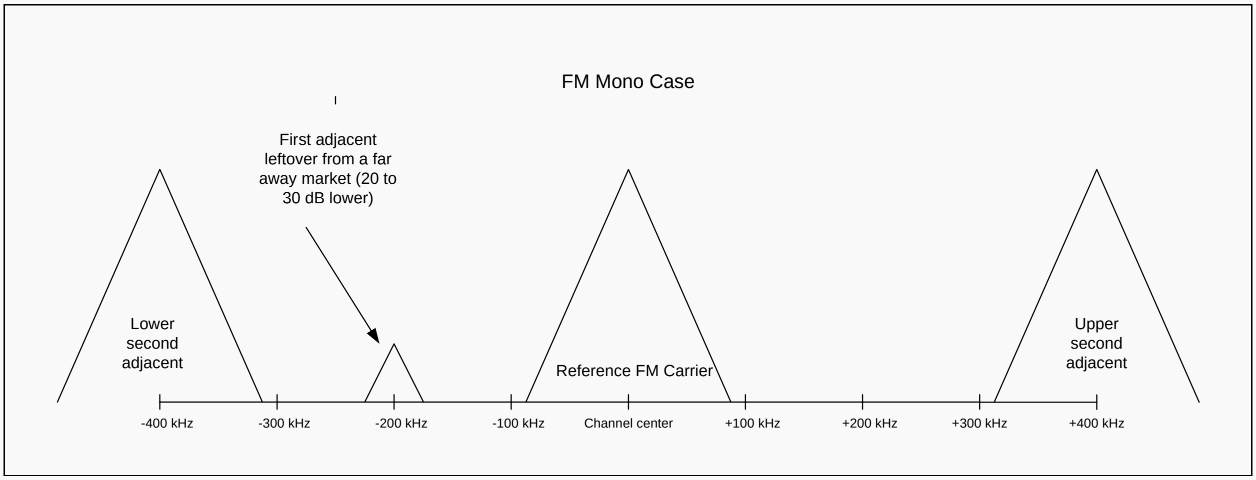
How much space does an FM channel really occupy? Is there any bandwidth left within the allotted 200 KHz?

The Carson Rule is used to establish FM signal bandwidth requirements. It states that an FM signal occupies (within 20 dB):

Occupied bandwidth = 2 (ΔF + (highest modulant frequency))
where: ΔF is the FM deviation

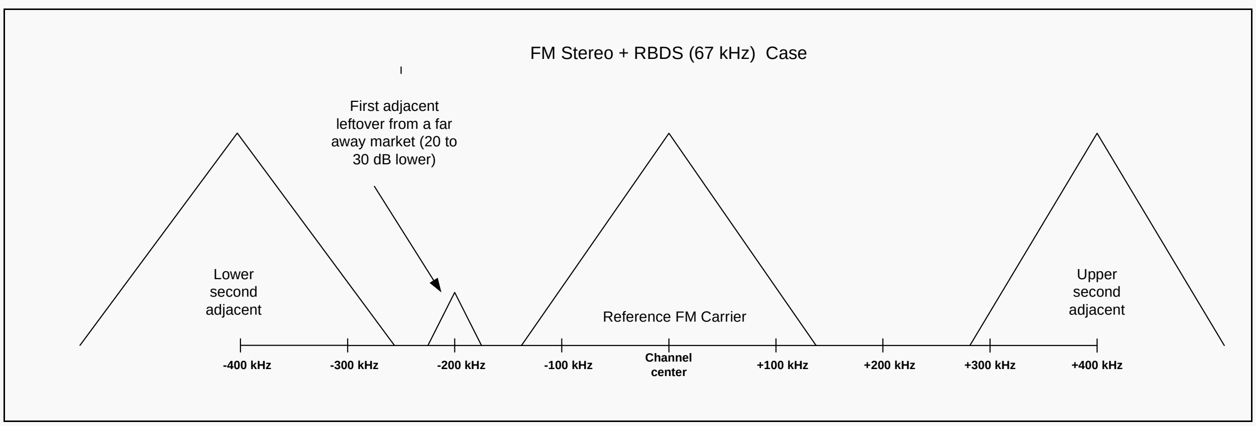
The highest modulant frequency clause demands clarification, as it varies depending on whether we are dealing with FM broadcast mono or FM MPX (Stereo) plus SCMO signals.

Mono service, based on a 15 kHz baseband audio, corresponds to:
2 x (75 kHz + 15 kHz) = 180 kHz



<u>Figure 1:</u> Wide spectrum view of FM Mono

Stereo service, based on MPX with 67 kHz SCMO, corresponds to:
2 x (75 kHz + 67 kHz) = 284 kHz



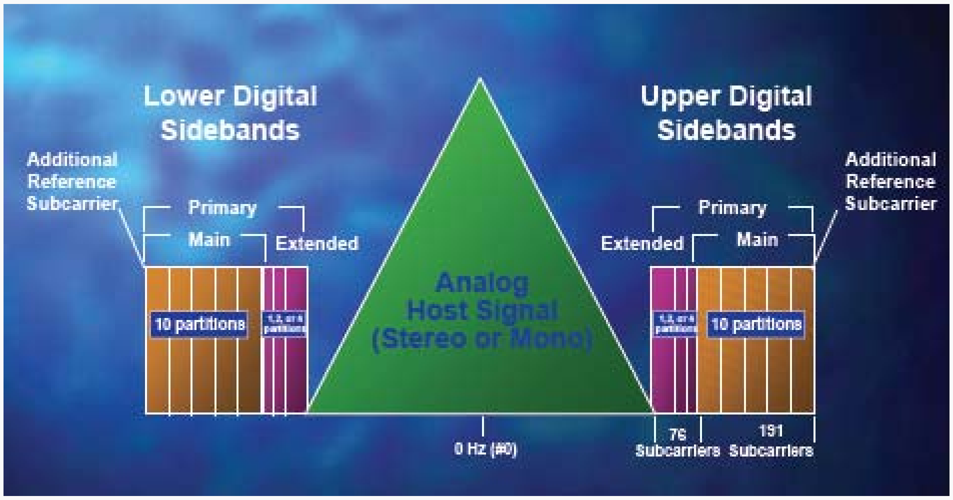
<u>Figure 2:</u> Wide spectrum view of FM Stereo + RBDS

How does stereo get away with this in a 200 kHz channel assignment? Simple: The first adjacent is never allocated in the same market.

OVERVIEW of IBOC

IBOC was designed to be spectrally compliant with analog FM. Although its name stands for In Band On Channel, it puts all its digital energy in the adjacent channel, so the name "IBAC" for In band Adjacent Channel would probably be more appropriate.

IBOC lays out two banks of OFDM carriers, one on either side of the host FM carrier.



<u>Figure 3:</u> wide spectrum view of FM IBOC (Main Carrier bank only)

Composition of the IBOC signal:

Bank			Start Freq	Stop Freq	Carriers	Modulation	Composition	Injection Level
Primary	Main	Lower	-198 kHz	-129 kHz	191	QPSK	OFDM	-41.4 dB
Primary	Main	Upper	+129 kHz	+198 kHz	191	QPSK	OFDM	-41.4 dB
Primary	Ext	Lower	-129 kHz	-102 kHz	76	QPSK	OFDM	-41.4 dB
Primary	Ext	Upper	+102 kHz	+129 kHz	76	QPSK	OFDM	-41.4 dB

- The main bank is carrying a total of 96 Kb/s
  - This also carries some Forward Error Correction codes of an undisclosed blend.

This technique is extremely convenient to implement; however, this convenience comes at a price, namely dealing with extremely adverse channel conditions:

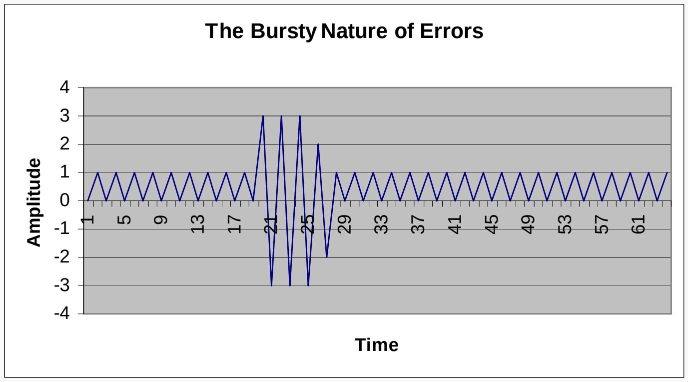
- FM host interference
- First adjacent interference
- Exposed to long delay multipath
- Narrow multipath dispersion bandwidth

To deal with this, IBOC designers had to use some of the most advanced communication technology:

- OFDM which uses:
  - Frequency interleaving
  - Time interleaving
  - Forward Error Correction
  - Analog service diversity

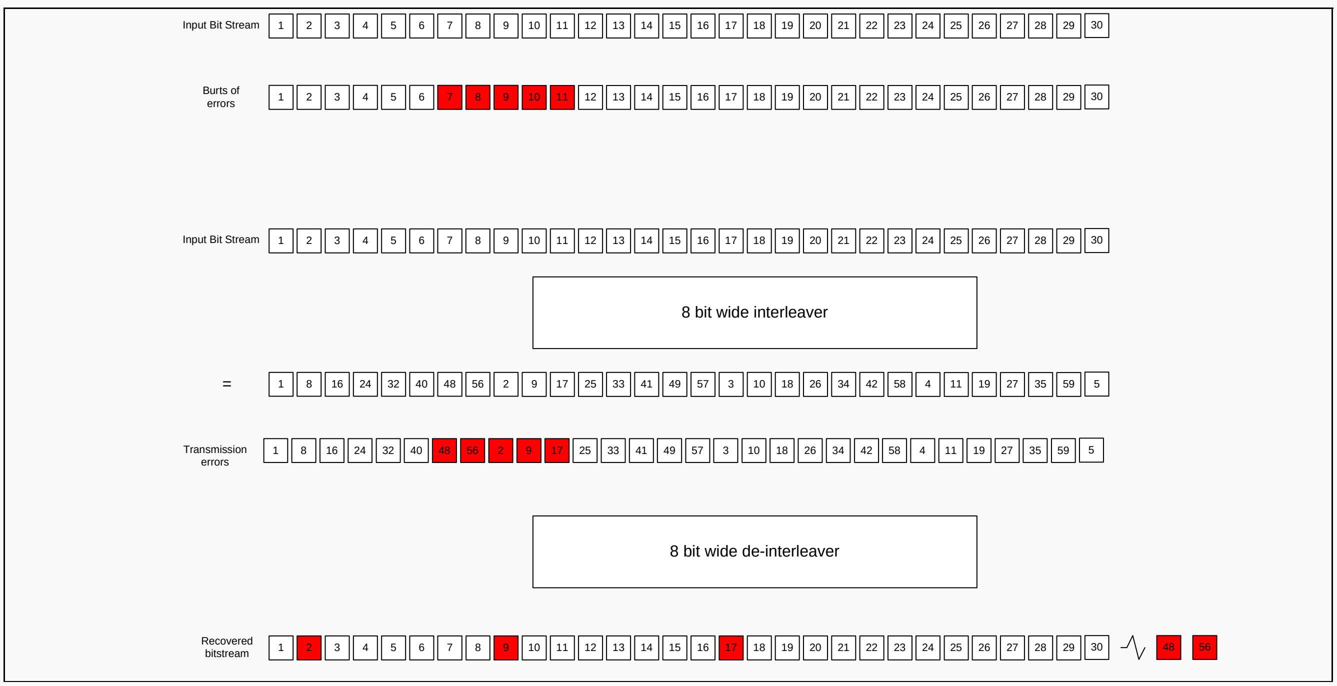
Time Interleaving

Time interleaving is a technique by which consecutive bits are spread in time so consecutive bits never travels sequentially, thus alleviating the effect of bursts of errors. The IBOC time interleaver is almost four seconds long, which means that consecutive bits may travel as far as four seconds apart.



For example, the following bit stream has to be transmitted with no more than one in-error bit by eight-bit word. Because of the bursty nature of errors, several bits in a row can be affected.

Using an eight-bit wide interleaver, the errors burst are broken up into individual errors that the error correction system can cope with.

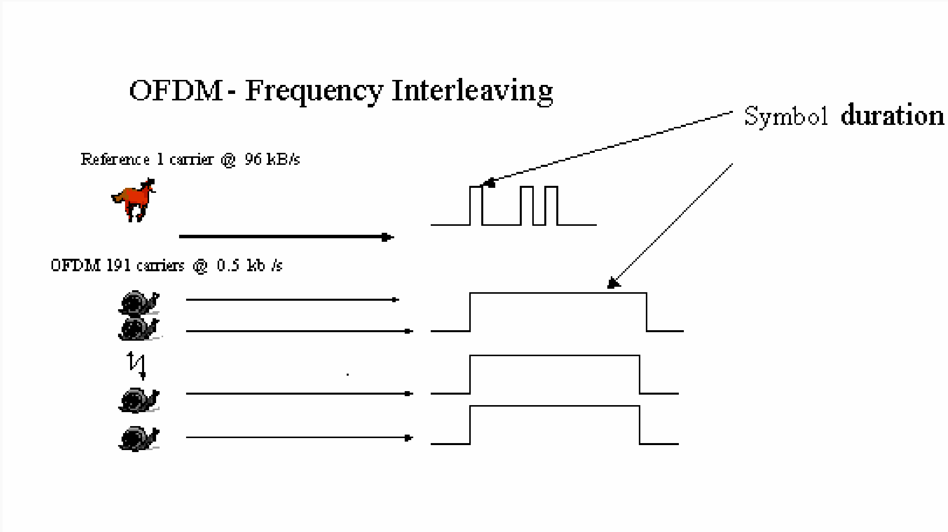


Frequency Interleaving

One of the chief enemies of digital transmission is multipath propagation, a phenomenon by which a signal is received from transmitter via different routes; most signal components reach the receiver antenna at different times (up to several microseconds apart).

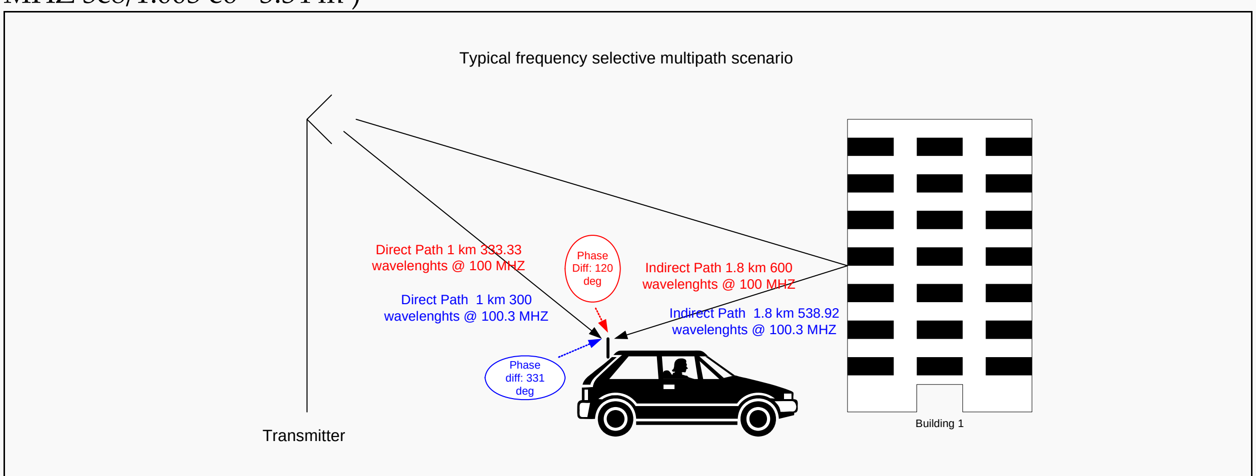
Frequency interleaving is aimed at increasing the signal resistance to multipath interference. This is a technique based on the division of the total payload that should be carried in a single carrier into hundreds of narrowband carriers.

By virtue of dividing the total payload into much smaller entities, the symbol duration (duration of a transmitted bit or bits group is1/freq) becomes much longer. Usually a much longer symbol duration permits the containment of the interference within the same symbol (avoid inter-symbol interference), which greatly increases the signal multipath resistance.



Frequency diversity bases its robustness in multi-path on the fact that multipath is a frequency-selective phenomenon; indeed, multipath fade is a direct function of the wavelength. A 300 kHz frequency delta equates a wavelength differential of 34 cm on a 3 m wavelength, assuming the air velocity factor is one.

(Wavelength = C (Speed of Light 300,000km/s)/ Frequency @ 100 MHz 3e8/1e6= 3m, @ 100.3 MHZ 3e8/1.003 e6= 3.34 m)



This equates to an arrival phase differential of about 40 degrees after a single wavelength of propagation. This is enough to substantially alleviate the adverse effect of multipath, as multipath fade can't simultaneously affect a large portion of the IBOC carrier's population. (This example is simplistic, as hundreds of significant multipath components can sometime be present in typical multipath-prone areas.)

Forward Error Correction

FEC is a technique by which a given number of overhead bits is added to a bit-stream to help the receiver correct errors that may have occurred in the transmission process. Normally the FEC can correct only a few incontiguous errors by packets of data (less than 1000 bits). Time interleaving has to be used to ensure that the FEC survives any significant burst of errors.

IBOC uses an undisclosed amount of FEC.

Analog Signal Diversity

IBOC normally reserves the first service as a replication of the analog FM host station. Because the analog and digital services are carrying the same audio contents, it is possible to use the analog service as a backup for the digital one. This raises the issue of timing, because the digital service has to be in synch with the analog host; however, mainly because of time interleaving, the digital service suffers a latency of about seven seconds. To address the issue, the analog host has to be delayed for an equivalent amount of time. The results of such a blend may be surprisingly successful, as properly timed streams blend seamlessly.

Psycho-Acoustic Audio Coding

As the bandwidth delivered by the main primary partitions of HD IBOC is 96 kb/s, the coding has to deliver acceptable audio quality within 96 kb/s in standard operation. If the station elects to broadcast a multi-cast of services, the data rate assigned for each service is even lower—a stereo service has to be delivered within 64 kb/s and a multi-cast (voice grade) channel within 32 kb/s. To deliver the results with so little bandwidth, the audio coding performance has to be comparable to AAC.

IBOC uses an undisclosed family of audio coding.

IBOC CHALLENGES
Analog Host interference

Mono service, based on a 15 kHz baseband audio, corresponds to:
2 x (75 kHz + 15 kHz) = 180 kHz.

Since Carson's rule defines the bandwidth requirement within 20dB, this interference level is well below the digital carriers' injection level and should not result in a significant carrier-to-interference ratio.

Stereo service, based on MPX with 67 kHz SCMO, corresponds to:
2 x (75 kHz + 67 kHz) = 284 kHz

Carson's rule dictates the bandwidth requirements, but to evaluate the level of a specific component of the signal, the FM equation has to be used. The level of the FM interference is an indirect function of the modulation index.

The worst component is the SCMO @ 67 KHz, which represents a modulation index of ($\Delta F/FM$-> 75/67= 1.4). As defined in the FM component amplitude equation, the relative amplitude of the component is driven by the Bessel coefficient corresponding to the modulation index $\beta(1.4) = 0.5$

$$y(y) = E.\sum_{-\infty}^{\infty} J_n(\beta).\cos(\varpi_0 + n\mu)t$$

As the SCMO injection level is 3% of the FM, the interference level will be 20 X log (0.03 x 0.5) = -36 dB, which may cause the loss of a few OFDM carriers as the carrier injection level is -41.4 dB. However, it will not affect a significant portion of the carrier population, so it has little effect on the Bit Error Rate. An aggregation of the five worst FM interference contributors delivered a composite interference level of -31 dB, which is just enough to start altering the overall IBOC service performance.

In conclusion, the host FM interference should be acceptable as long as the FM injection level is tightly controlled.

Potential Interference from the First Adjacent FM Channel

In Canada, Industry Canada BPR-3 dictates the protection ratios assigned to FM stations. The first adjacent is protected up to a desired-to-undesired (D/U) ratio of 6 dB, which means that the F50,10 interference contour of the potential interferer can't intersect the F(50,50) service contour of the protected station with a D/U signal ratio of less than 6 dB. Although the Canadian FM allotment plan minimizes these occurrences, that level of interference is present in some of Canada's major markets. The area where this coverage overlap is present at a D/U ratio of 6 to 10 dB is limited to the fringe of the FM host coverage.

Because the injection level of the IBOC signal is – 20 dB, IBOC is likely to suffer interference in the presence of a first adjacent of borderline amplitude. The impact of this interference remains to be studied.

Potential Interference from a Second Adjacent FM Channel

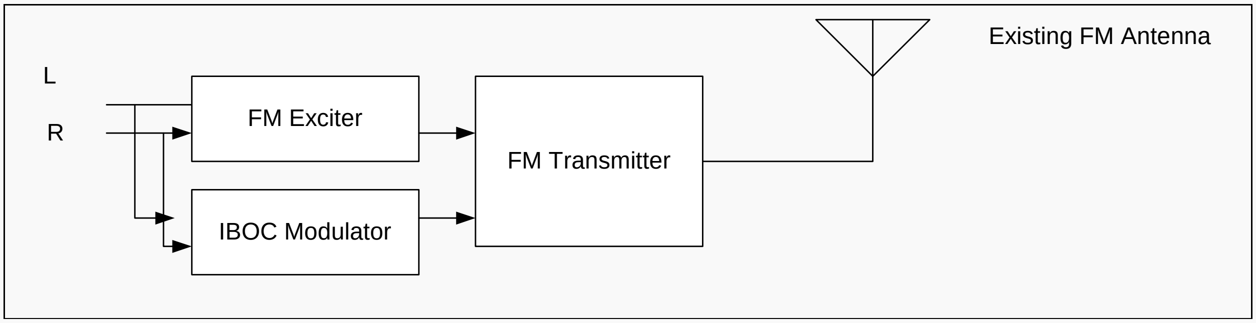
In Canada, Industry Canada BPR-3 dictates the protection ratios assigned to FM stations; the first adjacent is protected up to a D/U ratio of -26 dB. This means that the F(50,10) interference contour of the potentially interfering station can't intersect the F(50,50) service contour of the protected station with a D/U signal ratio of less than -26 dB—in other words, the interfering second adjacent can be 26 dB (400 times) stronger than the protected signal . Although the Canadian FM allotment plan minimizes these occurrences, as with the first adjacent, that level of interference is present in some of Canada's major markets. Again, the area where this coverage overlap is present at a D/U ratio of -26 dB is limited to the fringe of the FM host coverage, but similarly adverse D/U ratios may be present in a significant part of the coverage.

The impact of second adjacent interference on IBOC's operation has also not yet been studied.

IBOC Interface to Existing Facilities

Low-level Combining

Low-level combining relies essentially on a common amplification technique, which means that both the host FM signal and the IBOC signals are amplified in the same Power Amplifier (PA). This method requires very good linearity from the PA part. Any non-linearity will result in intermod products that are likely to interfere with adjacent FM stations. Most PAs cannot handle common mode amplification at rated output power; instead, they have to be operated in the most linear portion of their transfer curve, which results in a substantial back-off (around 6-10 dB). However, some advanced pre-distortion and linearization techniques can be used to alleviate the amount of back-off that has to be used to meet intermod specifications (4 to 6 dB).

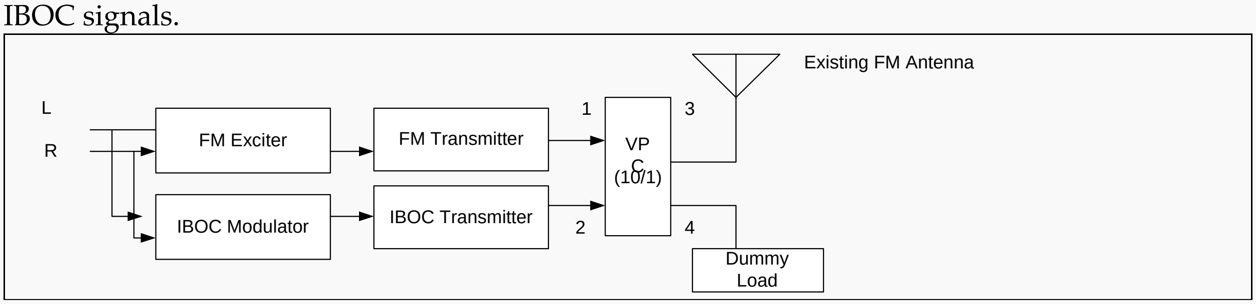


As IBOC adds about 1% to the total channel power, its power contribution is negligible so the power rating of the antenna is normally not an issue. However, because IBOC requires bout 200 kHz more bandwidth than conventional FM, antenna system frequency response may become problematic, especially in transmitter sites using narrow-tuned combiners.

Implementing low-level combining is unlikely to be feasible in an existing transmitter.

High-level Combining

High-level combining is based on the use of a distinct power amplifier for the host FM and the IBOC signals.



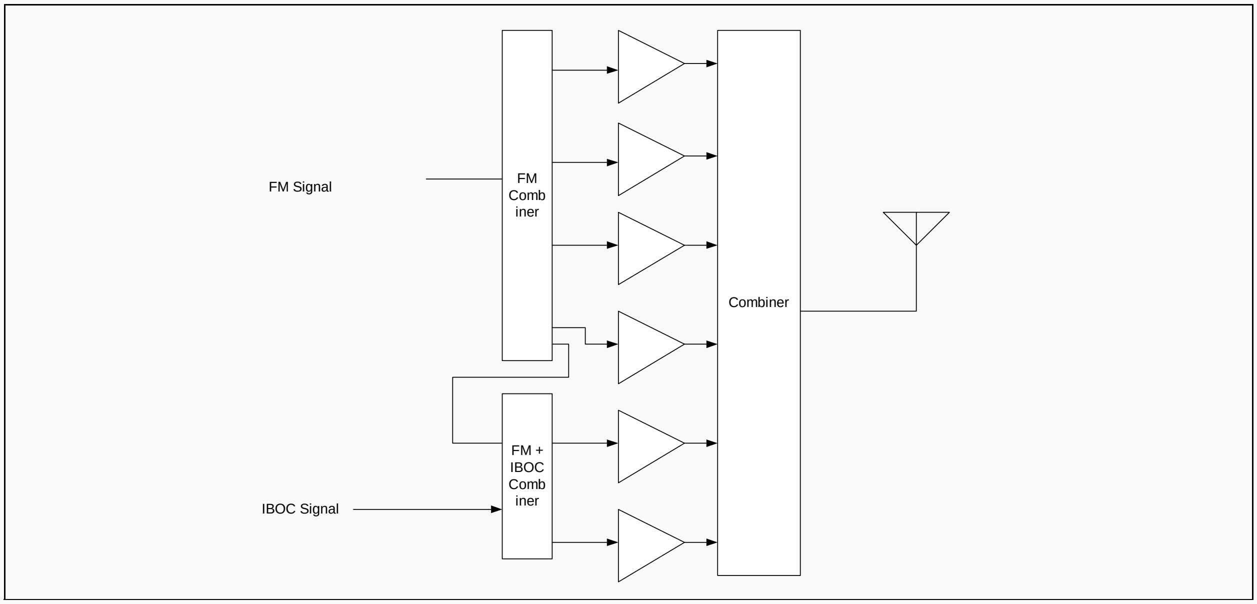
Both signals are combined before reaching the antenna. This technique uses an IBOC power injector, which is essentially an inverted directional coupler that is not frequency-selective. Its power ratio is selected to minimize the loss on the host path (port 1 to 3), typically 0.5 dB, allowing the host to still keep its original coverage using the existing transmitter. Such an injector does, however, offer a loss of about 10 dB on the IBOC path (port 2 to 3).

This process involves 90% of the IBOC power being dissipated in port 4 (as well as 10% of the FM host power), which is connected to a dummy load. Due to the fact that the IBOC injection level is 1%, the PA required for the IBOC remains much smaller than the analog host.

This approach is particularly practical when IBOC is retrofitted in an existing FM station.

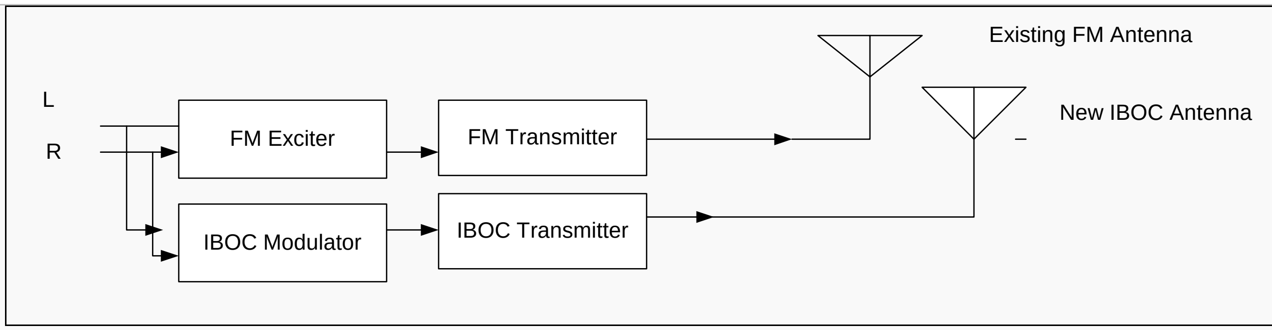
Split-level Combining

Split level combining is a mixture of low- and high-level combining, based on the hybrid use (IBOC + FM) of only a small part of the PA. Most of the PA modules are fed with the FM host signal at full rated power, while a few modules are carrying both IBOC & FM with some substantial back-off. The resulting composite back-off of the entire transmitter is mitigated by the fact that the majority of the modules are running at full power.
This approach is appropriate when the whole FM transmitter is getting renewed.



Separate Antennas

The use of separate antennas is a technique in which two distinct transmitters and two discrete antennas are used to carry both FM and IBOC signals. This technique has the advantages of requiring very little IBOC transmitter power and imposing no additional loss to the host transmitter. Its application is cumbersome, as both antennas have to have similar radiation patterns (vertical and horizontal) and must also be installed very close in aperture so their coverage is more or less equivalent.



The use of separate antennas is a viable alternative in the specific case where towers have the necessary free aperture at roughly the same elevation as the existing FM antenna. Because the IBOC antenna operates at a low power, it doesn't add any significant mechanical load to an existing tower.

CONCLUSION

IBOC represents an innovative way to carry radio programs making use of a piece of the spectrum that wasn't meant to be used, thanks to a series of technological developments. It opens new opportunities, such as the possibility of offering the audience a multicast program totally unrelated to the main program.

This paper highlighted a few of the challenges any IBOC implementer will have to face.

How well IBOC will deal with the RF environment, managed within Canadian rules, remains unknown.

The pilot test that will take place this summer will shed some light on some of the issues raised here. It will allow us to learn and explore the pros and cons of adding IBOC to existing CBC radio stations.

It is important to remember that HD Radio really consists of two separate and unique radio station signals. There are several methods available to allow transmission of both signals simultaneously. However, the best method for its implementation depends of the station's individual situation.

The results of the pilot will tell us the advantages and disadvantages of implementing an FM stations with IBOC. This CBC project is endorsed by Industry Canada and the Digital Radio Coordination Group (a sub-group of DRRI), which are looking forward with interest to seeing the outcome of this initiative.

The regulatory issues must also be examined, as the current regulatory framework doesn't even recognize the existence of IBOC. If HD Radio becomes a Canadian reality, broadcasters will have to ensure the regulations in place enable them to take full advantage of the possibilities offered by this new transmission vehicle.

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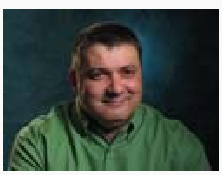
Glossary

FM	Frequency Modulation
HD Radio	US Digital Radio Broadcast standard
IBIQUITY Digital Corporation	Holders of the intellectual property of HD Radio
DRB	Digital Radio Broadcast
RBDS	Radio Digital Broadcast Standard, North American standard for digital services over analog FM broadcast transmission
OFDM	Orthogonal Frequency Division Multiplex
Frequency diversity	Occupying more than one frequency for the same service
FEC	Forward Error Correction
Psycho-acoustic audio coding	Audio coding based of a model of the human hearing system.
Modulation Index	Ratio between an FM deviation and the modulant frequency.
D/U Ratio	Ratio between a desired signal and an undesired one
PA	Power amplifiers
DRRI	Digital Radio Rollout Incorporated Canadian consortium whose mission is to promote digital radio broadcasting



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