

IBOC Technology

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Abstract: *In-band on-channel (IBOC) is a hybrid method of transmitting digital radio and analog radio broadcast signals simultaneously on some frequency. However, by putting RF energy outside of the normally defined channel, interference to adjacent channel stations is increased when using digital sidebands. The addition of the digital sidebands works better in the United States, where the FM broadcast band channels have a spacing of 200 kHz, as opposed to the 100 kHz that is normal elsewhere. The 200 kHz spacing means that in practice, stations having concurrent or adjacent coverage areas will not be spaced at less than 400 kHz. Outside of the US, spacing can be 300 kHz, which causes problems with the IBOC digital sidebands. IBOC does allow for multiple program channels, though this can entail taking some existing subcarriers off the air to make additional bandwidth available in the modulation baseband. On FM, this could eventually mean removing stereo. On AM, IBOC is incompatible with analog stereo, and any additional channels are limited to highly compressed voice, such as traffic and weather. Eventually, stations can go from hybrid mode (both analog and digital) to all-digital, by eliminating the baseband monophonic audio.*

Keywords: Binarized Neural Networks (BNNs), Stochastic gradient descent (SGD), Binary Optimizer (Bop), Graphics processing unit (GPU)

I. INTRODUCTION

In-band on-channel (IBOC) is a hybrid method of transmitting digital radio and analog radio broadcast signals simultaneously on the same frequency and increased when using digital sidebands. The addition of the digital sidebands works better in the United States, where the FM broadcast band channels have a spacing of 200 kHz, as opposed to the 100 kHz that is normal elsewhere. The 200 kHz spacing means that in practice, stations having concurrent or adjacent coverage areas will not be spaced at less than 400 kHz. Outside of the US, spacing can be 300 kHz, which causes problems with the

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II. ARCHITECTURE OF IBOC

The first, and currently only, digital technology approved for use on AM and FM broadcast frequencies by the Federal Communications Commission in the United States, is the proprietary HD Radio system developed by iBiquity Digital Corporation, which transmits energy beyond the allotted ± 100 kHz FM channel. This creates potential interference issues with adjacent channels. This is the most widespread system in use, with approximately 1,556 stations transmitting HD radio in the US, plus over 800 new multicast channels (as of Jan 2010). There is a one-time license fee to iBiquity Digital, for the use of its intellectual property, as well as costs for new equipment which range from \$50,000 to \$100,000 US (2010) per station.

A. FMeXtra

The other system is FMeXtra by Digital Radio Express, which instead uses subcarriers within the existing signal. This system was introduced more recently. The system is compatible with HD Radio in hybrid mode, but not in all-digital mode, and with RBDS. The stereo subcarrier can be removed to make more space available for FMeXtra in the modulation baseband. However, the system is not compatible with other existing 67–92 kHz subcarriers which have mostly fallen into disuse. The system is far less expensive and less complicated to implement, needing only to be plugged into the existing exciter, and requiring no licensing fees. FMeXtra has generally all the user features of HD Radio, including multicast capability; the ability to broadcast several different audio programs simultaneously. It uses the aacPlus (HE-AAC) codec. FMeXtra can control listening with conditional access and encryption.

B. DRM

Digital Radio Mondiale allows for simultaneous transmission of multiple data streams alongside an audio signal. The DRM mode for VHF provides bandwidths from between 35 Kbit/s to 185 Kbit/s and up to four simultaneous data streams, allowing 5.1 surround DVD quality audio to be broadcast alongside other multimedia content - images, video or HTML content are typical examples. While it is not backwardly compatible with existing FM receiver equipment, with broadcasts digitally encoded using HE-AAC or xHE-AAC, this ability to operate within the internationally agreed FM spectrum of 88-108 MHz makes DRM a viable candidate for future adoption when countries begin to switch off their analogue broadcasts.

C. HD Radio Broadcasting

iBiquity also created a mediumwave HD Radio system for AM, which is the only system approved by the Federal Communications Commission for digital AM broadcasting in the United States. The HD Radio system employs use of injected digital sidebands above and below the audible portion of the analog audio on the primary carrier. This system also phase modulates the carrier in quadrature and injects more digital information on this phase-modulated portion of the carrier. It is based on the principle of AM stereo where it puts a digital signal where the C-QUAM system would put the analog stereo decoding information.

D. Cam-d

CAM-D is yet another method, though it is more of an extension of the current system. Developed by AM stereo pioneer Leonard R. Kahn, It encodes the treble on very small digital sidebands which do not cause interference to adjacent channels, and mixes it back with the analog baseband. Unlike the other two, it is not intended to be capable of multichannel, opting for quality over quantity. Unlike the HD system iBiquity calls "hybrid digital" the CAM-D system truly is a direct hybrid of both analog and digital. Some engineers believe that CAM-D may be compatible with analog AM stereo with the right engineering.

Critics of CAM-D point to several drawbacks:

1. Being primarily analog, the system will be just as subject to artificial interference and noise as the current AM system
2. There are virtually no receivers available for the system and at present, no major manufacturer has announced even the intention to begin production of them; and
3. The cost of retrofitting with CAM-D is more than that of simply buying a new, HD-ready solid-state transmitter.

III. IBOC MODES OF OPERATION

There are three IBOC modes of operation. IBOC allows transition from analog to digital through a Hybrid and Extended Hybrid mode of operation, before adopting an All-Digital mode of operation. The digital signal is modulated onto a large number of subcarriers, using orthogonal frequency division multiplexing (OFDM), which are transmitted simultaneously.

A. Hybrid Mode

In this mode the digital signal is inserted within a 69.041 kHz bandwidth, 129.361 kHz on either side of the analog FM signal. The IBOC Hybrid mode digital signal is transmitted in sidebands either side of the analog FM signal and each sideband is approximately 23 dB below the total power in the FM signal. The hybrid sidebands are referred to a Primary Main (PM) sideband. The host analog signal may be mono or stereo, and may include subsidiary communication channels. The total power of the digital sidebands is 20 dB below the nominal power of the FM analog carrier with power relative to the total analog FM power of ≈ 41.39 dB/kHz.

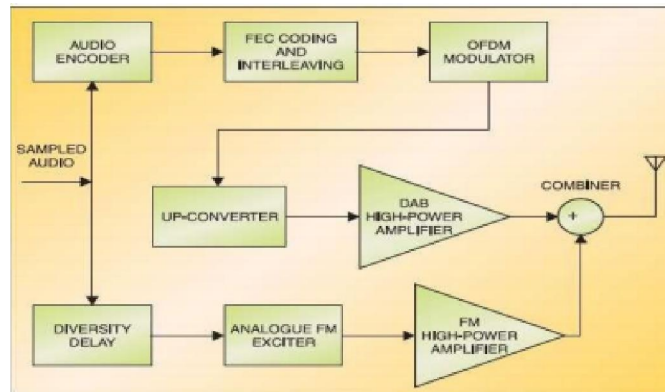


Figure 1: IBOC Transmitter

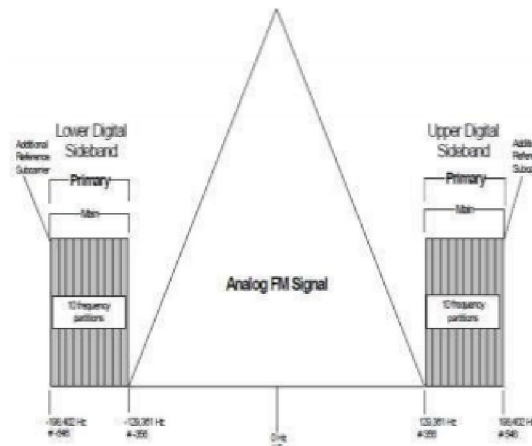


Figure 2: Hybrid mode

B. Extended Hybrid Mode

This mode includes the hybrid mode and additional digital signals are inserted closer to the analog signal, utilising a 27.617 kHz bandwidth, 101.744 kHz on either side of the analog FM signal. Analog FM Signal 129,361 Hz 198,402 Hz 115,553 Hz (# 318) 0 Hz (# 0) Additional Reference Subcarrier Primary Primary Upper Digital Sideband Extended Main in Extended 101,744 Hz (# 280) 122,457 Hz (# 337) (# 546) (# 356) -198,402 Hz (# -546) -129,361 Hz (# -356) 115,553 Hz (# -318) -101,744 Hz (# -280) -122,457 Hz (# -337) 10 frequency partitions 10 frequency partitions 1, 2, or 4 frequency partitions 1, 2, or 4 frequency partitions Lower Digital Sideband Additional Reference Subcarrier The IBOC Extended Hybrid mode digital sidebands are extended towards the analog FM signal to increase digital capacity. The extended hybrid sidebands are referred to as Primary Extended (PX) sidebands. The total power of the digital sidebands is 20 dB below the nominal power of the FM analog carrier with power relative to total analog FM power of ≈ 41.39 dB/kHz.

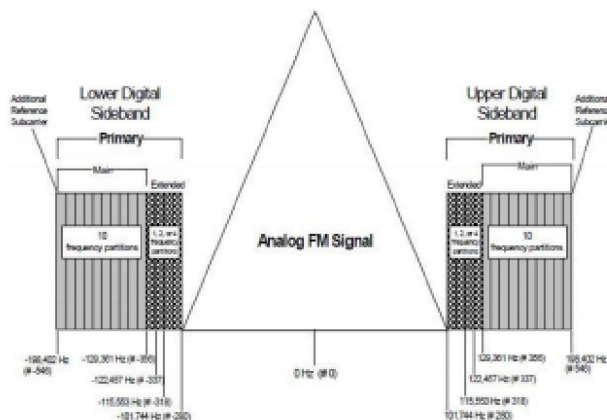


Figure 3: Extended hybrid mode

All digital mode of the Hybrid and Extended Hybrid modes. 198,402 Hz (# 546) 101,744Hz (# 280) 129, This mode replaces the analog signal with additional digital signals and also includes the digital signals 361Hz (# 356) 0 Hz 69,404Hz 97,021 Hz Main Extended Main Primary Secondary Secondary Primary Lower Digital Side band Extended Extended Main Protected Protected 101,381 Hz (# 279) (# 0) (# 267) (# 191) -101,381 Hz (# -279) -69,404 Hz (# -191) -97,021 Hz (# -267) -101,744 Hz (# -280) -129,361Hz (# -356) -198,402 Hz (# -546) 10 frequency partitions 10 frequency partitions 10 frequency partitions 10 frequency partitions 4 frequency partitions 4 frequency partitions 4 frequency partitions 4 frequency partitions 4 frequency partitions 4 frequency partitions Upper Digital Sideband 12 subcarriers Additional Reference Subcarrier Additional Reference Subcarrier Additional Reference Subcarrier Additional Reference Subcarrier 12 subcarriers With IBOC All Digital, the primary digital sidebands are extended as in IBOC Extended Hybrid and the analog signal is removed and replaced by lower power digital secondary sidebands, thus expanding the digital capacity. The total power of the digital sidebands is 10 dB below the nominal power of the replaced FM analog carrier with power relative to total analog FM power of ≈ 31.39 dB/kHz.

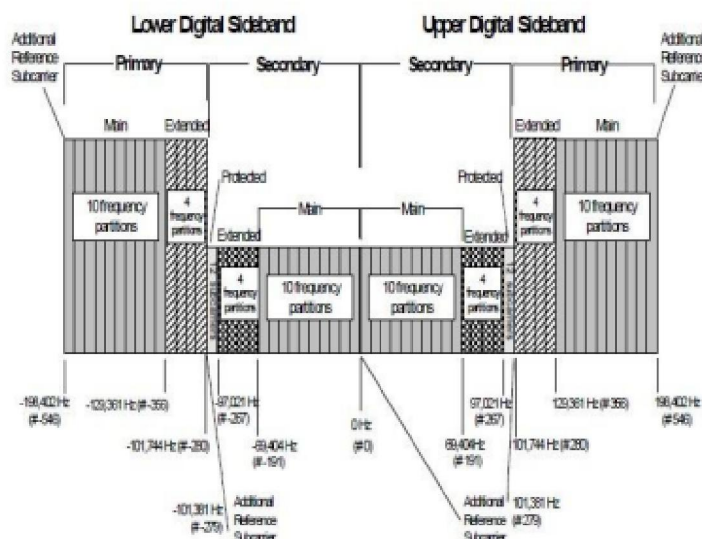


Figure 4: IBOC Digital mode

In radar, used to locate and track objects like aircraft, ships, spacecraft and missiles, a beam of radio waves emitted by a radar transmitter reflects off the target object, and the reflected waves reveal the object's location. In radio navigation systems such as GPS and VOR, a mobile receiver receives radio signals from navigational radio beacons
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whose position is known, and by precisely measuring the arrival time of the radio waves the receiver can calculate its position on Earth. In wireless radio remote control devices like drones, garage door openers, and keyless entry systems, radio signals transmitted from a controller device control the actions of a remote device. In order to overcome the problem of interference between multiple users within the same beam, multiple user detection technology was proposed with the basic idea of processing all user information as useful information instead of as interference information.

In radio communication systems, information is carried across space using radio waves. At the sending end, the information to be sent is converted by some type of transducer to a time-varying electrical signal called the modulation signal. The modulation signal may be an audio signal representing sound from a microphone, a video signal representing moving images from a video camera, or a digital signal consisting of a sequence of bits representing binary data from a computer. The modulation signal is applied to a radio transmitter. In the transmitter, an electronic oscillator generates an alternating current oscillating at a radio frequency, called the carrier wave because it serves to "carry" the information through the air. The information signal is used to modulate the carrier, varying some aspect of the carrier wave, impressing the information on the carrier. Different radio systems use different modulation methods:

- AM (amplitude modulation) – in an AM transmitter, the amplitude (strength) of the radio carrier wave is varied by the modulation signal.
- FM (frequency modulation) – in an FM transmitter, the frequency of the radio carrier wave is varied by the modulation signal.

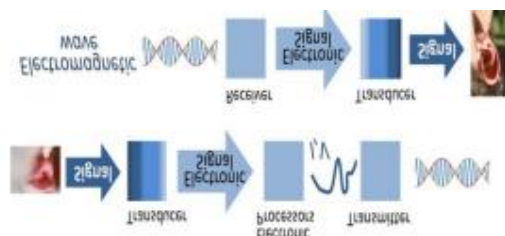


Figure 5: Radio communication

Many other types of modulation are also used. In some types a carrier wave is not transmitted but just one or both modulation sidebands. The modulated carrier is amplified in the transmitter, and applied to a transmitting antenna which radiates the energy as radio waves. The radio waves carry the information to the receiver location.

At the receiver, the radio wave induces a tiny oscillating voltage in the receiving antenna which is a weaker replica of the current in the transmitting antenna. This voltage is applied to the radio receiver, which amplifies the weak radio signal so it is stronger, then demodulates it, extracting the original modulation signal from the modulated carrier wave. The modulation signal is converted by a transducer back to a human-usable form: an audio signal is converted to sound waves by a loudspeaker or earphones, a video signal is converted to images by a display, while a digital signal is applied to a computer or microprocessor, which interacts with human users.

The receiver uses tuned circuits to select the radio signal desired out of all the signals picked up by the antenna, and reject the others. A tuned circuit (also called resonant circuit or tank circuit) acts like a resonator, similarly to a tuning fork [6]. It has a natural resonant frequency at which it oscillates. The resonant frequency of the receiver's tuned circuit is adjusted by the user to the frequency of the desired radio station; this is called "tuning". The oscillating radio signal from the desired station causes the tuned circuit to resonate, oscillate in sympathy, and it passes the signal on to the rest of the receiver. Radio signals at other frequencies are blocked by the tuned circuit and not passed on.

DAB is generally more efficient in its use of spectrum than analogue FM radio, and thus can offer more radio services for the same given bandwidth. However the sound quality can be noticeably inferior if the bit-rate allocated to each audio program is not sufficient. DAB is more robust with regard to noise and multipath fading for mobile listening although DAB reception quality degrades rapidly when the signal strength falls below a critical threshold, whereas FM reception quality degrades slowly with the decreasing signal, providing effective coverage over a larger area. The original version of DAB used the MP2 audio codec.

In spectrum management, the bands that are allocated for public DAB services, are abbreviated with T-DAB, where the "T" stands for terrestrial.

C. Benefits of DAB

DAB devices perform band-scans over the entire frequency range, presenting all stations from a single list for the user to select from. DAB can carry "radio text" (in DAB terminology, Dynamic Label Segment, or DLS) from the station giving real-time information such as song titles, music type and news or traffic updates, of up to 128 characters in length. This is similar to a feature of FM RDS, which enables a radio text of up to 64 characters.

The DAB transmission contains a local time of day and so a device may use this to automatically correct its internal clock when travelling between time zones and when changing to or from Daylight Saving. DAB is not more bandwidth efficient than analogue measured in programmes per MHz of a specific transmitter (the so-called link spectral efficiency), but it is less susceptible to co-channel interference (cross talk), which makes it possible to reduce the reuse distance, i.e. use the same radio frequency channel more densely. The system spectral efficiency (the average number of radio programmes per MHz and transmitter) is a factor three more efficient than analogue FM for local radio stations. For national and regional radio networks, the efficiency is improved by more than an order of magnitude due to the use of SFNs. In that case, adjacent transmitters use the same frequency. The specialised nature, limited spectrum and higher cost of DAB broadcasting equipment provides barriers to unlicensed ("pirate") stations broadcasting on DAB. In cities such as London with large numbers of unlicensed radio stations broadcasting on FM, this means that some stations can be reliably received via DAB in areas where they are regularly difficult or impossible to receive on FM because of interference from unlicensed radio stations. Mono talk radio, news and weather channels and other non-music programs need significantly less bandwidth than a typical music radio station, which allows DAB to carry these programmes at lower bit rates, leaving more bandwidth to be used for other programs. DAB transmitters are inevitably more expensive than their FM counterparts. DAB uses higher frequencies than FM and therefore there may be a need to compensate with more transmitters to achieve the same coverage as a single FM transmitter. DAB is commonly transmitted by a different company from the broadcaster who then sells the capacity to a number of radio stations. This shared cost can work out cheaper than operating an individual FM transmitter.

This efficiency originates from the ability a DAB network has in broadcasting more channels per transmitter/network. One network can broadcast 6–10 channels (with MP2 audio codec) or 10–18 channels (with HE AAC codec). Hence, it is thought that the replacement of FM-radios and FM-transmitters with new DAB-radios and DAB-transmitters will not cost any more compared with new FM facilities. It is also argued that the power consumption will be lower for stations transmitted on a single DAB multiplex compared with individual analog transmitters.

D. Disadvantages of DAB

The reception quality during the early stage of deployment of DAB was poor even for people who live well within the coverage area. The reason for this is that DAB uses weak error correction coding, so that when there are a lot of errors with the received data not enough of the errors can be corrected and a "bubbling mud" sound occurs. In some cases, a complete loss of signal can happen. This situation has been improved upon in the newer DAB+ version that uses stronger error correction and as additional transmitters are built. As with other digital systems, when the signal is weak or suffers severe interference, it will not work at all. DAB reception may also be a problem for receivers when the wanted signal is adjacent to a stronger one. This was a particular issue for early and low-cost receivers. A common complaint by listeners is that broadcasters 'squeeze in' more stations per ensemble than recommended by:

- Minimizing the bit-rate, to the lowest level of sound quality that listeners are willing to tolerate, such as 112 Kbit/s for stereo and even 48 Kbit/s for mono speech radio (LBC 1152 and the Voice of Russia are examples).
- Having few digital channels broadcasting in stereo.

The nature of a single-frequency network (SFN) is such that the transmitters in a network must broadcast the same signal at the same time. To achieve synchronization, the broadcaster must counter any differences in propagation time incurred by the different methods and distances involved in carrying the signal from the multiplexer to the different transmitters. This is done by applying a delay to the incoming signal at the transmitter based on a timestamp generated at the multiplexer, created taking into account the maximum likely propagation time, with a generous added margin for safety. Delays in the audio encoder and the receiver due to digital processing (e.g. deinterleaving) add to the overall

delay perceived by the listener. The signal is delayed, usually by around 1 to 4 seconds and can be considerably longer for DAB+. This has disadvantages:

- DAB radios are out of step with live events, so the experience of listening to live commentaries on events being watched is impaired;
- Listeners using a combination of analogue (AM or FM) and DAB radios (e.g. in different rooms of a house) will hear a mixture when both receivers are within earshot.

Time signals, on the contrary, are not a problem in a well defined network with a fixed delay. The DAB multiplexer adds the proper offset to the distributed time information. The time information is also independent from the (possibly varying) audio decoding delay in receivers since the time is not embedded inside the audio frames. This means that built in clocks in receivers can be precisely correct.

IV. IBOC CAPABILITIES

IBOC enables the broadcaster to select the desired audio quality and data transmission rate however, as expected, there is a trade-off between audio quality and the data transmission rate. The audio quality and data trade off in the three modes is summarised in Table 1: The audio quality at 96 kb/s is near CD quality but in Hybrid mode this only allows 1 kb/s for data. IBOC allows the bit rate to be adjusted in 8 kb/s steps. By transmitting audio at the satellite DARS3 bit rate of 64 kb/s, additional data capacity, exceeding that of the current generation of mobile phones (9 ñ 19kb/s), is available. At times when audio quality is not as important, the audio bit rate may be reduced to as low as 48 kb/s but audio quality will be reduced to near telephone audio quality. IBOC incorporates a 4.5 second delay between the analog and digital audio signals. The receiver initially acquires the analog signal and takes a few seconds to begin to decode the audio on the digital sidebands. If 10% of the digital data blocks sent are corrupted during transmission, the IBOC receiver reverts to the analog signal. This is referred to as the iblend-to analog feature of IBOC. The blend process is perceived to have the same quality as the analog audio and the process itself does not degrade the audio quality below that of analog. Field tests indicate that Hybrid FM IBOC digital coverage is comparable to analog coverage but IBOC reception can be obtained in areas where the analog service is currently of an unacceptable quality due to interference such as co-channel interference, impulse noise and multipath fading. The enhancements claimed over traditional analog FM broadcasting include:

- Almost full immunity from typical FM multipath reception problems;
- Significantly improved full stereo coverage;
- Flexible data casting opportunities;
- Efficient means for FM broadcasters to begin the transition to digital broadcasting
- Use of OFDM in IBOC allows on-channel digital repeaters. It is expected that there will be a trade off in audio signal to-noise ratios in some areas where 1st adjacent (IBOC) stations overlap, but this is only expected. The iBiquity field tests conducted with eight FM broadcasting stations in the US, concluded that digital coverage with one hundredth the power (-20dB) of analog, extended to the 45 - 50 dB signal.

V. CONCLUSION

IBOC is capable of transmitting audio services and a variety of wireless data services. At the basic level, it will enable broadcasters to transmit data related to digital audio programming, including song title, artist and station information. The initial receiver applications are expected to include the ability to display simple text information related to audio programming. Additional data services are expected to include the delivery of paging-like services, including traffic, weather, sports scores, stock quotes and target.

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