"ON CHANNEL" REPEATER IMPLEMENTATION FOR HD RADIO™ COVERAGE IMPROVEMENT

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ABSTRACT

This paper will be a discussion of the key considerations one needs to evaluate when developing implementation plans for enhanced HD Radio coverage using "on-channel" repeaters or gap fillers. We will examine the implications, challenges and limitations of receiving a HD Radio signal off the air, and repeating the digital-only portion on the same channel. There will be a review of antenna isolation required, practical power levels, the benefits and limitations of adaptive echo cancellation and impact on receiver performance. This paper will explore space planning, power levels and the ongoing costs. This discussion is based on the real world experience with similar projects and networks Harris has been involved with around the world.

CURRENT SITUATION

HD Radio implementation in the US is climbing the slope of the adoption curve from an interesting technology that only has the attention of early adopters to one that has a broader appeal in Americans favorite listening environments. The often heard radio slogan "…take us along, at home, at work or in the car…" plays well for analog FM but might have to be modified to include "…unless you are in a large building, behind a hill or at the fringe of the coverage…" for HD Radio. Clearly listeners have come to expect that radio coverage is almost universal, and their favorite station comes in well just about everywhere they are. To have the same level of success stations enjoy today in FM analog, HD Radio coverage needs to match the analog host closely. The reception situation is partially a result of the very low level of the HD Radio signal as it compared to the analog FM signal; currently FM stations are allowed to broadcast digital signals at 1% of their analog power. This power level typically offers usable service in the primary unobstructed coverage area of the station; however reception issues are seen inside some buildings, and areas of low signal coverage. Broadcasters are investigating ways to improve coverage of the digital signal including elevating the digital sideband levels, which we will not be discussing, and the use of multiple transmitters in a Single Frequency Network (SFN) approach.

FM BOOSTERS

Analog FM boosters have been tried in many variations over the years, with varying levels of success. The basic principle is that in areas of low main transmitter signal level, one could operate another, frequency locked transmitter that could supplement the coverage of the main transmitter. The most successful method of implementation includes a degree of terrain shielding that obscures the line of site from the main transmitter to the target reception area. In this case potential for interference between the two transmitters is the lowest given the high levels of physical isolation as shown below in Figure 1.

The area of interference can be minimized and controlled, but at some locations there will be interaction between the main transmitter and the

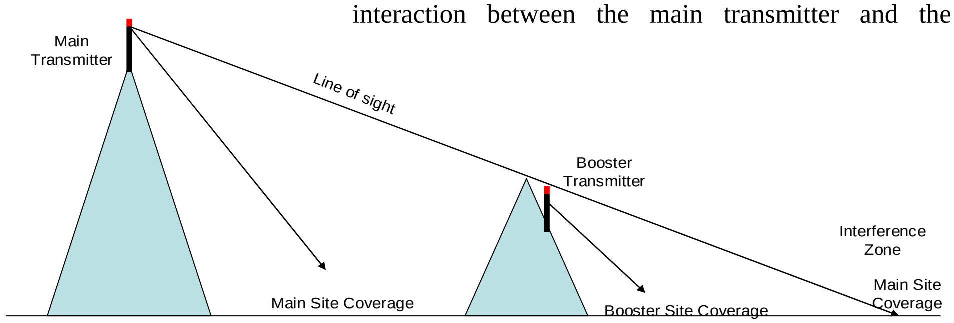


Figure 1

booster. In analog, is it critical to align both the transmitter frequency, and the modulation/audio. Systems such as the Harris Flexstar™ digital FM exciter, and the Harris Intraplex Synchrocast™ system use GPS precision to lock the carrier frequencies and to control the timing of the audio transmitted to allow for simultanious arrival at the interference zone to make a near seamless handoff between the main transmitter to the booster. In this approach a complete, but lower powered, transmission system is located at the booster site, and both sites are connected via T1 or IP networks for audio delivery, and system timing. This solution is proven to work well in FM analog and has had some experemental use with HD Radio, however it can be complex to implement a well-timed network.

DIGITAL TRANSMISSION

One of the benefits often outlined for digital transmission of broadcast signals is robustness in the presence of multipath or ghosting interference. Most of us have expereienced the effects of multipath reception on an FM analog radio while driving in the car, especially at a traffic light. At one point the reception of our favortie station is just fine, and as we roll up a few more feet, the signal gets very noisy and may even disapear. This is due to the arrival of the same signal but at different times, one is directly from the main transmitter, and the other is a reflection from a large building or mountain often at a diferent phase form the first. These two signals mix in the radio receiver causing destructive RF interference at the carrier frequency and/or selective fading of the baseband modulation components. which causes loss of audio or audio distortion.

Contempory digital transmission systems have been designed to address this common issue, and bring the promise of nearly interference-free reception. This is acomplished by using multi-carrier COFDM digital modulation, which addresses the constructive reception of multiple signals by providing the frequency diversity required to overcome channel fading. COFDM systems also use guard time intervals in the coding of the data modulation to provide a degree of immunity to errors in the presence of echoes and reflections. The guard interval is inserted prior to the beginning of each symbol transmitted. As long as the echo or multipath delayed data is received during the guard interval period, the data can be demodulated without interference. The longer the guard interval, the greater imunity to echos or multipath over a wider range of distances, however it negativly impacts the data payload of the signal, so one must carfully balance the improved immunity with the reduced data capacity to reach optimal performance. It is because of this interference mitigation technology that digital networks can support the use of seamless single frequency networks.

DIGITAL GAP FILLERS

Digital transmission networks have been deployed for various standards of digital radio and TV around the world and offer some interesting alternatives to increasing usable coverage and lowering deployment costs. In the DVB-T standard for example, a system that employs COFDM modulation, completely seamless network coverage using, high power main transmitters, lower power synchronized SFN sites, and also “on frequency” GAP fillers is provided for. A gap filler is a system which retransmits the “off air” signal from another transmitter to supplement coverage in certain areas of weak or minimal coverage. Since the gap filler receives the signal off the air it requires no STL, exciter or encoding equipment, thereby reducing the cost and complexity of the installation from an equipment perspective. Since there are not any T1 or IP circuits used, the on-going operating expense is also reduced.

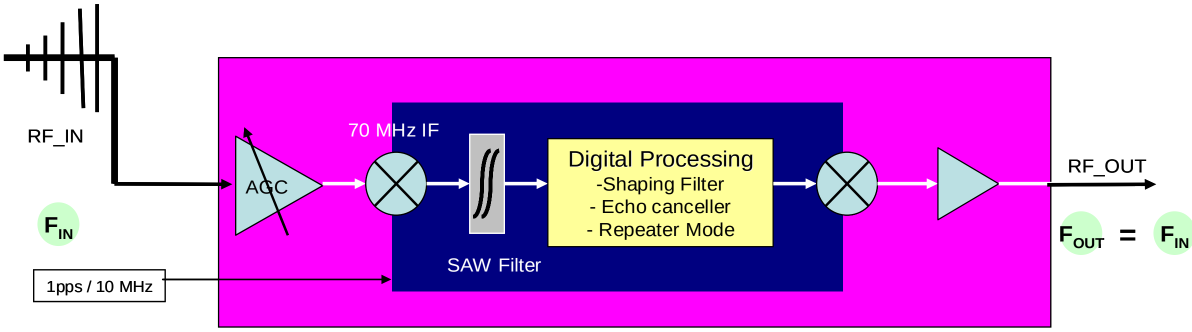


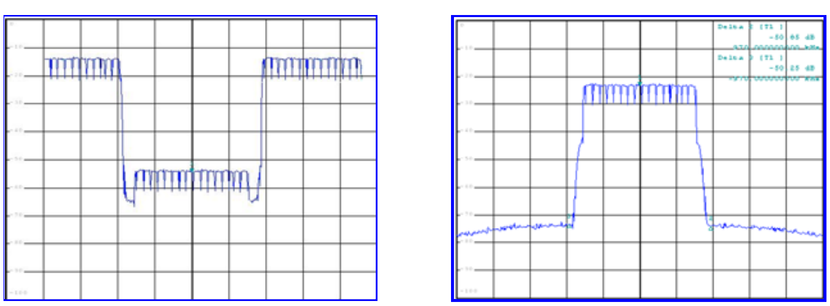
Figure 2

But wait you say, re-transmitting the same signal on the same channel will be just like placing a live microphone in front of a speaker, it will just feedback! How do I make sure I only re-transmit my signal, and not adjacent channels? Both of these issues are addressed thanks, in part, to some new technology utilized in the digital world. First, let's take a look at the basic block diagram of a digital gap filler system (Figure 2). The input is a sensitive, frequency agile, receiver front end that can be set to a specific channel across the entire FM band. The incoming signal is shifted to an intermediate frequency, and passes through a high quality analog-to-digital converter. It is important to note that all the signal processing utilized in the gap filler is implemented with digital circuits. Once digitized, the desired signal is filtered to remove out-of-band products, and unwanted adjacent channels. In addition, digital, adaptive, echo cancellation is employed to null out echoes from the output of the system fed back in to the input. The digitized signal also receives linear and non-linear digital pre-correction to compensate for distortions in the final amplifiers in the system. (It should be noted that in a gap filler mode, the power output is limited by network planning, and by the limit of the echo cancellation to mitigate feedback. Typical systems are not more than 100- 200 watts of digital power). The corrected signal is then converted back to analog, and converted back to the same frequency as the input for use as an "on-channel" gap filler repeater, or it can be shifted to another frequency if used as a translator. For this system to work there are two key technologies that are used which we will explore in more depth.

DIGITAL FILTERING

In addition to the RF filtering at the input stage, and the SAW filter on the IF, the gap filler employs powerful digital shaping filters to create the very sharp filtering needed to capture the desired signal to be repeated and reject the adjacent signals. In fact, it is the digital approach to filtering that is a key enabler to make the on-channel gap filler work, where analog technology was not able to work. The amount of digital filtering used is dependant on the proximity of the adjacent channel that is to be removed. While the system can support a large mount of filtering to remove unwanted signals, this level of processing induces more delay, and as we remember from the discussion about guard intervals, timing of the signal arrival at the desired receive site is important. If there is too much delay (beyond the guard interval) the system will not perform as desired.

So filtering vs. delay is a trade-off to be balanced when designing a SFN system using Gap filler technology. Figure 3 below shows the results of the powerful digital filtering targeting the desired input signal with two stronger adjacent COFDM DVB-T channels.



Input **Output**

Figure 3

DIGITAL ADAPTIVE ECHO CANCELLING

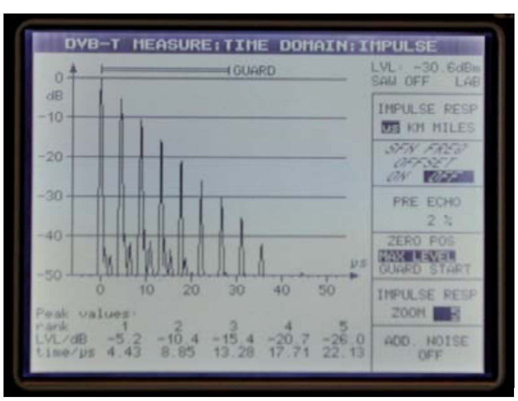
Adaptive echo cancellation is a powerful feature needed to get the most out of an on-channel gap filler system since it allows for the highest RF output level on the same channel as the input without feedback. It should be noted that there are some situations where simplistic on-channel repeaters without digital processing and echo cancellation could be used, however those situations need significant levels of isolation between the Rx and Tx antennas as well as terrain shielding to make the system work in places like subway tunnels and underground parking garages, where there is almost no main signal present. Using the same live microphone and speaker analogy as mentioned before, you can think of adaptive echo cancellation much like the adaptive feedback reduction processors used in PA systems such that one could use a much higher level of system gain with a live microphone. In the case of the gap filler, the echo cancelation system looks for an RF signal that matches the desired input source, but is time delayed from that source. As discussed before, there is a minimal amount of time delay through the digital processing of the gap filler, so any output signal that would be seen on the input would be delayed in time equal to the amount of processing time used in the performance of filtering, echo cancellation, and digital pre-correction. The digital processing in the gap filler would identify the echo as undesirable, and digitally remove it such that it could not be re-amplified.

In addition to simple echoes that come from the output of the gap filler and are seen on the input, reflected signals from the gap filler could also present themselves as an undesirable echo, and not the main signal to be repeated. It is important that the digital processing be capable of cancelling multiple echoes to ensure proper operation of the gap filler. In Figure 4 below, the left graph shows the results of using an on-channel gap filler without echo cancellation, and the right graph shows the resulting reduction of echoes using the echo cancellation signal processing.

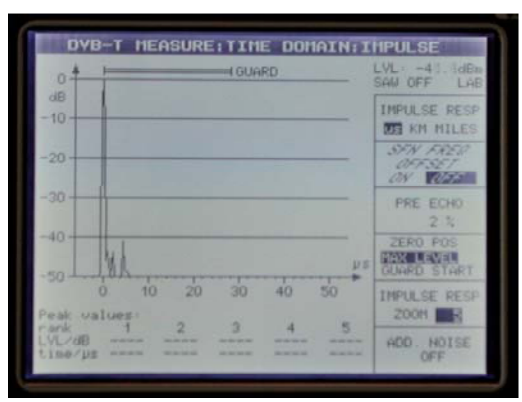
HD RADIO APPLICATION

HD Radio has both similarities and differences from some of the other standard digital radio and TV transmission standards used globally and commented on in this paper. The use of gap filler technology must be amended in order to deliver the desired results needed for HD Radio. The biggest difference is that although HD Radio uses COFDM much like DAB and DVB-T, there are two redundant sets of digital carriers very closely spaced above and below the analog signal. The HD Radio transmission is a hybrid of analog and digital signals. This is not the case for DAB or DVB-T. However, by applying the same technology, one could provide a high quality, cost effective method for increasing HD Radio coverage.

We believe there are three possible implementations that could be addressed using the gap filler approach. One would be to repeat both the analog host, and the digital sidebands on the same channel. Slightly different would be to repeat the analog host and the digital sidebands on a different frequency such as done with a translator, and thirdly would be to repeat only the digital sidebands from the primary station. If we consider the first two options, the translator is the most straight forward, a digital approach provides excellent performance for both the host analog and the digital



Echo canceller OFF



Echo canceller ON

Figure 4

side bands, and it also has the benefit of very powerful filtering to reject adjacent channels that traditional analog translators may not have been able to process effectively.

Repeating both the analog host and the digital sidebands on the same channel is a more complex issue to address since analog reception does not have the inherent capability to reject multiple signals that the digital platforms do. While this may work with some success in areas of good terrain shielding, more study needs to be done to characterize the performance and results with a broad range of receivers.

If we reflect on the goal we are trying to reach, which was stated as a way to increase HD Radio levels to more closely match the coverage enjoyed in analog, then we are only interested in increasing the signal level of the digital carriers, and not repeating the analog carrier.

In order to successfully repeat the digital portion of the HD Radio signal, a system would have to use powerful digital processing to implement very sharp filters to reject both the adjacent channels on either side of the desired signal, and "notch" the host analog signal so that it would not be repeated and induce additional interference. Figure 5 depicts a typical, hybrid FM HD Radio signal. The output of the digital-only gap filler is shown in figure 6.

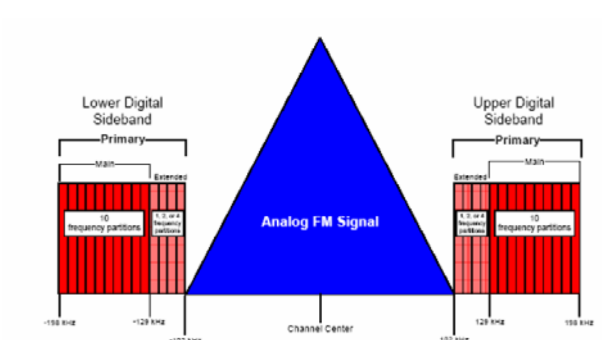


Figure 5

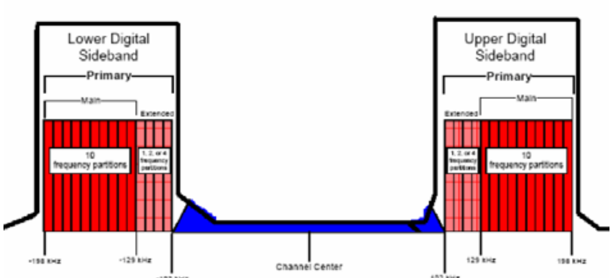


Figure 6

Getting the digital-only signal out of the gap filler is only part of the implementation process. Care should be given to pick a gap filler site that has a solid look-angle to the main transmission site for good reception, but one that also has a good view of the desired coverage area. Much like analog boosters, planning, and the use of a directional antenna will likely be needed to direct the gap filler signal to cover the area lacking main site coverage.

One other key point to plan in the implementation of a digital-only gap filler is the ratio of digital signal to analog signal. Simplistically one could assume that the goal would be to match the 1% digital ratio that currently exists at the main site and authorized by the FCC. If authorized in the future, higher sideband levels may be desirable to provide robust cover a reasonable area around the gap filler site, and is possible with properly designed gap filler applications. Without carful planning the ratio of digital sideband power to analog power could be much higher in the vicinity of the "digital only" gap filler. Managing the power of the gap filler and the related digital to analog signal ratio will be important to ensure proper FCC compliance and to avoid interference to both the host analog signal, and adjacent FM channels. Recent studies however have indicated that analog radios can work reliably with relatively high levels if digital subcarriers present, in some cases approaching 100% of the analog with minimal impact. More tests are in process to determine the ability of FM receivers to maintain acceptable analog FM reception in the presence of higher than normal digital sideband levels.

It should also be noted that each gap filler site must be licensed, and follow the appropriate rules of the FCC. Boosters and gap fillers are intended to compensate for areas that fall with in a station's protected contours, but due to some local terrain shielding or buildings, may yield less than desired coverage. In other words the gap filler could only be used to fill in rather than extend coverage of a station.

CONCLUSION

The transition to digital broadcasting opens up new and effective methods of improving usable coverage of terrestrial transmission networks. Technology however does not provide all the answers; careful network planning is required to ensure the gap filler increase usable coverage rather than destroying it. Key considerations to be evaluated when looking at gap fillers as a method of improving HD Radio coverage are:

- Technology can be leveraged from other digital standards and applications
- Some signal shielding is still needed for effective operation
- Gap fillers offer low cost of operation
- Powerful digital filtering is a must
- Adaptive echo cancellation is needed to provide higher output power
- Careful implementation planning is required for solid results

REFERENCES & ACKNOWLEDGEMENTS

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