The Low Delay, Echo Cancelling Gap Filler

David Neff
Axcera, LLC

1) Introduction

Terrestrial broadcast television transmission has historically been accomplished by emitting a very high power signal from one antenna, situated at the highest possible location above the intended receive sites. This seems sensible; broadcasting is meant to be a "one to many" communications method, and one transmit site is usually the most economical way to accomplish this. However, one emitter can not always provide good coverage of the population. A variety of factors can inhibit the ability to receive a signal:

- Terrain shielding
- Shielding from tall buildings
- Attenuation of walls when indoor reception is desired
- Mobile receivers – moving through shadowed areas
- Distance from the emitter, combined with the above factors

In the days of analog television, the only practical solution for coverage gaps was to use a translator or transposer. These units retransmitted the signal on a different channel to fill in the gaps and extend the coverage. An on-channel gap filler solution was generally not practical, due to the possibility of co-channel interference between the main signal and the repeated (time delayed) signal at the receiver, as well as the high isolation that would be required between the transmit and receive antennas of the gap filler. So coverage enhancement required translators and licenses for multiple frequencies.

Thankfully, with today's digital signal processing techniques, on channel gap fillers are practical and very useful. Digital TV standards accommodate single frequency networks easily, and digital processing techniques have reduced the transmit/receive isolation requirements of gap fillers significantly. This paper will describe gap fillers and their applications.

2) Need for gap fillers

The diagram (Figure 1) below shows some examples of where gap fillers would be useful. They are generally used to fill in gaps in the planned coverage area, not to extend the coverage beyond its original borders. Power levels are typically limited to 100-200 watts or less, mainly due to the isolation requirements between the transmit and receive antennas of the gap filler. Without the benefit of digital echo cancellation, gap fillers would be generally impractical; most would be limited to less than 1 watt.

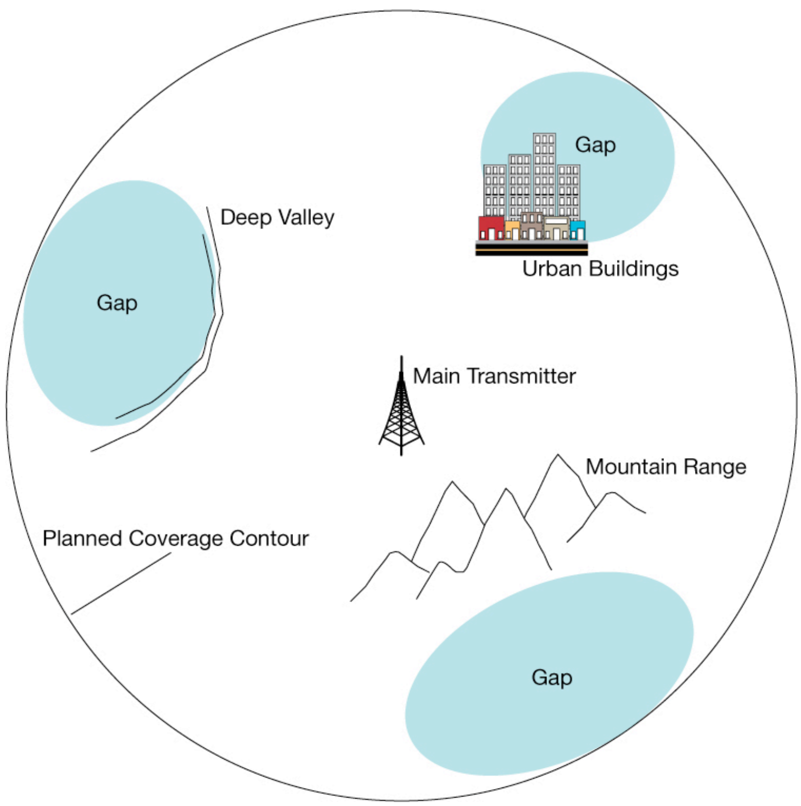

Figure 1

3) Why is low delay important?

Gap fillers retransmit signals on the same channel as the originating transmitter. It is the function of the receiver (set top box or television) to deal with the potential presence of two (or possibly more) co-channel signals (such as from both a main transmitter and a gap filler) without allowing them to interfere with each other and degrade reception. This receiver capability depends on the multiple signals being received at very short time intervals from each other. The mechanics of how delayed co-channel signals are handled differ between some digital TV standards, but the low delay requirement is the same.

- In single carrier systems like ATSC, a time domain equalizer eliminates the interfering effect of the time delayed signals and provides reliable reception in the presence of multiple co-channel signals. However, the equalizer is limited in its capabilities. Typically, ATSC equalizers offer time delay equalization windows of +/- 50 uS or so. ATSC Recommended Practice A/74:2010 lists recommended target performance criteria for handling echo delays from -40 to +50 uS. (Note that a negative delay figure indicates that the lower amplitude signal arrives at the receiver before the reference (higher amplitude) signal.)

- In OFDM systems like DVB, ISDB-T and others, multiple co-channel signals are handled differently. These systems incorporate guard intervals, which are inserted as a fractional portion of each symbol period. Essentially, the guard interval provides a length of time during each symbol period where the receiver discards any information that is received (such as time delayed multipath or a time delayed signal from a co-channel transmitter). Guard interval duration can be selected in the transmitter modulator, but longer guard intervals reduce the available payload data rate for the information transmission. Therefore, a tradeoff is made between available data rate and robustness against co-channel interference. Typical guard interval lengths are in the range of 20 – 200 uS.

In either case, these delay ranges are not very long – much too short to allow for a gap filler to demodulate and remodulate signals. If the gap filler creates a long delay with respect to the main signal, it will go beyond the equalizer capability (ATSC) or beyond the guard interval duration (OFDM). Axcera's gap filler products have an insertion delay of between 5 and 10 uS, depending on the settings of the internal filter. This low delay characteristic allows the successful use of gap fillers in either ATSC or OFDM systems.

It should be noted that the co-channel interference and the need for low signal delay through the gap filler described here assumes that signals are received by the viewer from both the main transmitter and a gap filler. This is not necessarily the case; terrain shielding could effectively block the main signal (a key reason for the gap filler in the first place). If that were the case, low delay would not be necessary, and a regenerative on channel repeater (demodulate/remodulate) could be used. However, this is a rare situation, and should not be counted on.

4) Why is echo cancellation important?

As previously stated, a key requirement for a gap filler is good isolation between the transmit and receive antennas. Ideally, the receive antenna would receive the signal from only the main transmitter and the transmit antenna would send the amplified gap filler output to only the receiver population to be covered. But in the real world, some of the transmit antenna radiation couples back to the receive antenna, and since it is at a much higher power level and in such close proximity to the receive antenna, problems occur. The feedback signal will have a delay relative to the incoming signal, and at the very least will contribute to frequency selective fading and multipath-like interference, degrading SNR and/or MER. In the worst case, if the feedback is at a high enough level, the regenerative effects can bring the loop into oscillation, rendering the system unusable.

Today's digital signal processing algorithms have allowed significant attenuation of this feedback effect, making higher power gap fillers possible. Echo cancellation of up to 40dB is achievable. This superior cancellation means that stable operation can be achieved even with a feedback (undesired) signal that is larger than the incoming (desired) signal! This capability eases the extreme input/output isolation requirement, and enables gap fillers at significant output power levels to be successfully realized.

5) Architecture – how a gap filler works

Below is a simple block diagram of a gap filler (Figure 2). The incoming RF signal is downconverted to a common IF frequency, then digitized by a high speed A/D converter. From there, a digital signal processor executes the echo cancellation algorithm before reconversion to analog and upconversion back to the original channel. The gap filler also provides for some linear and nonlinear precorrection for the power amplifier that follows and includes a bandpass filter to minimize out of band emissions.

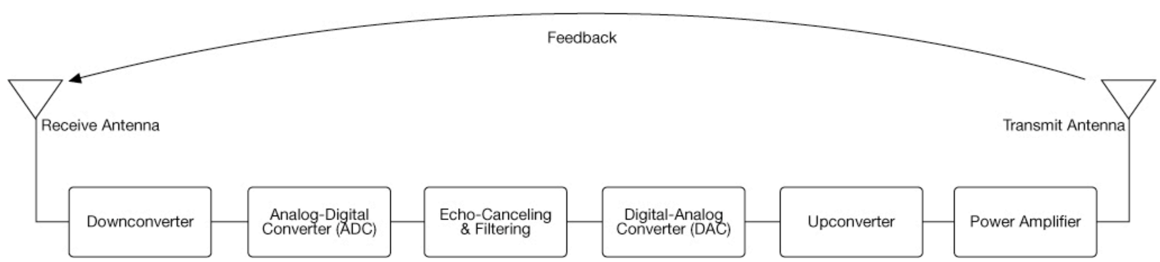

Figure 2

The echo cancellation algorithm has an adjustable time window that should be set for optimum results. The Axcera gap filler time window is 5 uS wide, and it can be set anywhere from 1.5 to 448 uS from the main signal; this allows the user to select the specific undesired multipath or other co-channel interference to be cancelled. The gap filler inherently also cancels its own feedback signal.

6) System Considerations – planning for a gap filler

The purpose of a gap filler is obviously to fill in "gaps" – areas of the intended coverage area that are not covered well with strong signals. To properly implement a gap filler solution, several important steps should be considered, and in many cases professional services will be needed in the planning process. Steps in the planning process include:

- **Identifying the location and size of the coverage gaps.** The best approach to this is to perform coverage analysis, which is done with computer software modeling. The models are equipped with digital maps of the area that include terrain information and in some cases clutter data (buildings, foliage, etc.). The coverage engineer inputs the relevant power level, frequency, antenna height and coordinates, and other information to produce a coverage map that shows predicted receive signal level contours (see Figure 3 below). This gives a strong indication of where the coverage gaps are likely to be. Additional confirmation or improvement of the model can be achieved by drive testing. This consists of driving throughout the coverage area with a mobile receiver and data logger package that provides actual receive level information. This data is then fed back to the computer model to "tune" it and improve its accuracy. The analysis tool will also allow modeling of proposed gap fillers and their effects.

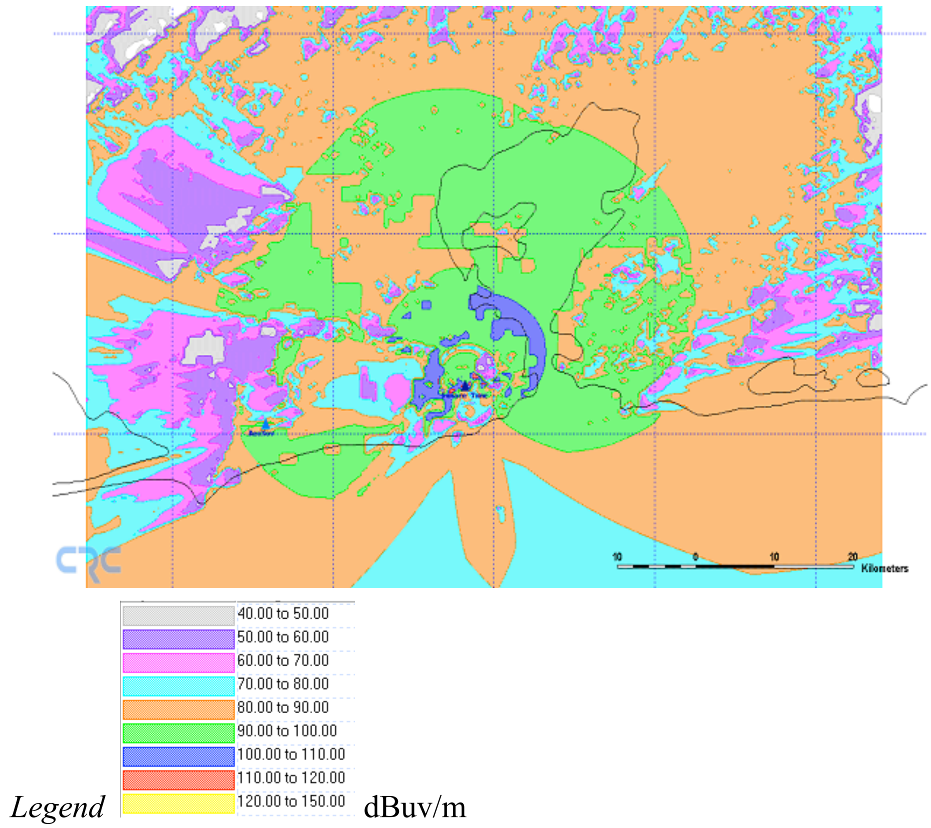

Figure 3

- **Determining the best solution to fill the gap(s), if any.** An on-channel gap filler solution is limited in most cases to 100-200 watts, so if a gap is too large to be covered by those power levels, multiple gap fillers or an off channel translator/transposer solution may be required. In addition, an economic analysis should be made to determine if the cost of implementing a coverage enhancement will be justified, based on the population affected.

- **Finding available sites –** A gap filler solution will ideally have a high location (tower, tall building rooftop, etc.) from which to operate. The coverage analysis will identify roughly where those sites should be located, and then identification of actual sites must be done.

- **Planning for isolation –** While a gap filler provides excellent cancellation of the feedback signal, minimizing the feedback by other means is still important. An ideal situation would be to have substantial physical separation between the receive and transmit antennas to minimize feedback. Other methods include using directional antennas (especially the receive antenna) and utilizing terrain shielding to help to block the feedback path.

- **Consider licensing requirements –** The regulations vary by country as to how a gap filler needs to be licensed, if at all. If it is used to fill in gaps in what was planned to be covered in the first place, it could be argued that no new license should be required. But that is not the case in many areas.

7) Summary

On channel, low delay, echo cancelling gap fillers have become a useful tool in solving coverage limitations without the need for additional channels. Advanced technology has enabled products that provide on channel signal retransmission with appreciable power levels, yet with low insertion delay and cancellation of feedback signals. With proper planning, these gap fillers can bring significant coverage enhancements to broadcasters.