# Digital On-Channel Booster for 8-VSB

by
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**Abstract:** There are many reasons to implement a DTV transmission system with DTV translators by broadcasters. In most cases, a translator system is implemented to enhance the DTV signal coverage that is limited by shadowing, multipath interference, and power. This paper reviews DTV translator technologies, discusses concerns and issues faced by today's DTV broadcasters, and proposes a new 8-VSB Digital On-Channel translator concept.

## Introduction

A translator in a DTV system can be viewed as a signal booster in a same channel or in a different channel. Typically, a primary DTV transmitter is used to transmit a high power signal over a wide area. However, due to shadowing and multipath issues in a channel, there may exist many holes and gaps with inadequate signal presence in the intended coverage area and create service issues,[4]. In such case, an ideal solution to enhance the signal coverage in the shadowed area is to implement a DTV translator system.

For a DTV translator that transmits on a different channel frequency, the technology is simple. In this case, the primary DTV signal is demodulated to a base-band signal, remodulated to another 8-VSB RF carrier, amplified, filtered, and transmitted on another channel frequency, [6]. The RF transmit power has a little impact on the translator's input received signal since the transmit and receive frequencies are different. The translator's output power feeding back into its input receiver can be limited to an acceptable level since its interference power can be controlled and filtered out for a proper operation. Such DTV translator that uses a different channel to repeat the primary main DTV signal, while technologically easy to implement since any delay throughput is acceptable, it uses up a valuable RF spectrum channels in the ever increasingly crowded UHF spectrum.

However, while promising an efficient use of the RF spectrum, a lot of technical issues must be considered for a proper operation of an on-channel booster system.

## On-Channel DTV Translator

For an on-channel 8-VSB booster, a same RF transmit frequency is used to boost the received 8-VSB signal. As seen in Figure 1, this has an inherent problem of becoming a potentially self-jamming system. Since the location of the output antenna is usually limited to a few hundred feet of its receiving antenna, the output transmit power can appear at the input antenna and jam its own input receiver.

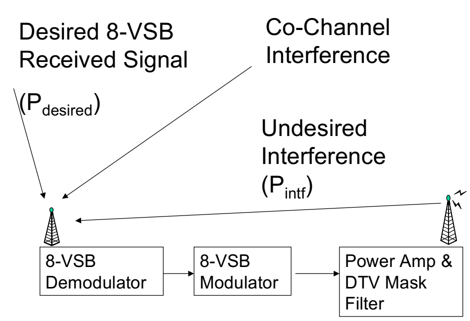


Figure 1. On-Channel Booster with Inherent Self-Jamming Issue

In this case, a physical separation between the on-channel booster's output transmitter antenna and its input receiving antenna must be established. This separation of the two antennas is typically achieved with a solid building, a rock or earth separation, or any signal isolating apparatus in the free air between the antennas.

An 8-VSB receiver typically requires a minimum of 15 dB of SNR in order to demodulate the desired 8-VSB signal. This means, then, the sum of all undesired signal and noise power has to be at least 15 dB lower than the desired input received signal power as described in equation (1). The undesired signals can arise from a co-channel interference; but, more predominantly, it is produced by the DTV on-channel booster's output transmit power leakage into its own input receiver.

$$SNR_{(rcvd)} > P_{(desired)}/P_{(undesired)} = 15 \text{ dB} \qquad (1)$$

This minimum requirement will be more difficult to establish if the on-channel booster is located so far away from the primary transmitter such that a faint and very small signal is received by the on-channel booster.

In other words, the on-channel booster is inherently limited to a distance between the main transmitter and the location of the on-channel booster. In addition a physical separation is required between the on-channel booster's output transmitting antenna and its receiving antenna. Once these two requirements are met, then following other technical concerns must be addressed for an On-Channel Booster.

**Analog On-Channel Booster**

For any modulated RF carrier, it can be translated in a same channel without first demodulating the signal to a base-band. A good example, as seen in Figure 2, is an NTSC on-channel booster system that demodulates the RF carrier to an Intermediate Frequency (I.F.) signal, band-pass filter, and up-convert to the same RF frequency. This system can afford a simple design, low throughput delay, and a low cost implementation.

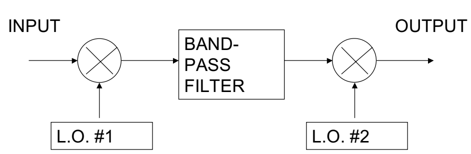


Figure 2 An Analog On-Channel Booster using an I.F. Band-Pass Filter

While this concept is applicable to a DTV translator for an on-channel or a different channel, it has an inherent difficulty in filtering out its adjacent channel signals or reject a co-channel interference signal. This is shown in Figure 3. In this case, a 3 channel DTV system is shown, the on-channel booster is selected for the center channel, and the output spectrum is captured. As can been in Figure 3A, the adjacent channels can be at different power levels. After band-pass filtering by the analog on-channel booster in Figure 3B, the output signal still contains some residual spectrum from the adjacent channels.

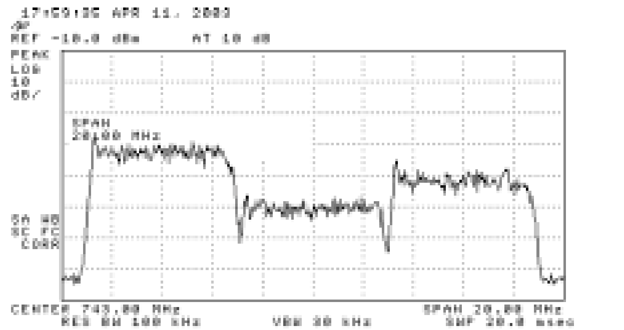


Figure 3A. Spectrum Before the Analog On-Channel Booster

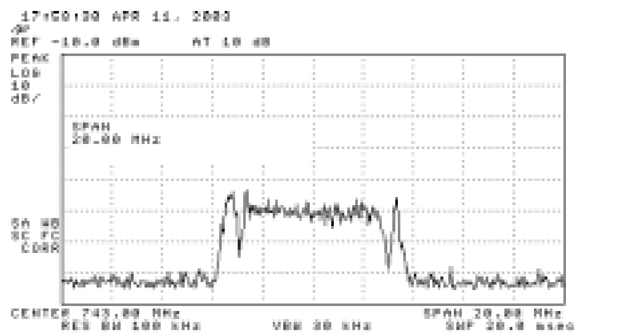


Figure 3B. Spectrum After the Analog On-Channel Booster

If the I.F. signal is filtered tight in an effort to filter out the adjacent channel signals, it can be made such that the output signal rejects the adjacent channel signals. But, it will undoubtedly degrade the SNR of the desired signal due to imperfect real-world implementation of the I.F. band-pass filter. Such filters will cause linear distortion on the signal due to group delay and magnitude response in its in-band I.F. filter characteristics.

In addition, the on-channel booster requires that the output transmit frequency to be phase-locked onto the primary transmit 8-VSB signal for it to be applicable to an 8-VSB system. Unless the carrier and symbol clocks are synchronized to the primary 8-VSB signal, consumer 8-VSB receivers will not be able to take advantage of the on-channel booster system since the unsynchronized primary 8-VSB transmitter signal will appear as noise.

Moreover, the analog on-channel booster scheme has no rejection capability of co-channel interference and no demodulator enhancement capability from such performance degrading effects as multipath or error due to channel noise. In fact, all received channel noise, channel multipath interference, and co-channel interference will be present at the output.

While all 8-VSB consumer receivers today include an equalizer in its demodulator to minimize the linear distortions created by the analog on-channel booster, the end result with the analog on-channel booster is a reduced coverage area for the broadcaster. It will have issues such as adjacent channel rejection, co-channel rejection, multipath interference rejection, and reduced noise margin. So, a great care must be applied when above issues are a concern. If above concerns are not an issue for some markets and some isolated cases, the analog on-channel booster does offer a choice.

There are advantages of using the analog on-channel booster. It offers a simple design, a low cost implementation and a low signal delay through the system. The simple design and low cost means that it will probably be reliable and affordable. The low throughput delay is an important issue since it is a critical requirement for any on-channel booster system. For a digital on-channel booster system, this is especially the problem. Unless the throughput delay is reduced to a manageable amount, the consumer DTV receivers will treat the primary signal as noise and cause degraded performance or not work at all.

For a consumer DTV receiver to work well, it is designed with an equalizer in its demodulator to combat channel multipath effects. Since the on-channel booster regenerates the output signal at the same frequency as the primary main 8-VSB signal, the consumer DTV receiver will demodulate both the main and the booster output signal at the same time, as indicated in equation (2).

$$S_{received}(t) = \alpha S_{primary}(t) + \beta S_{booster}(t-\tau) \qquad (2)$$

Where

$S_{primary}(t) = \cos(2\pi f_o t + \Phi(t))$ = time varying amplitude and phase modulated 8-VSB signal

$f_o$ = carrier frequency

$\Phi(t)$ = information carrying amplitude and phase modulation of 8-VSB signal

$\alpha$ = amplitude of 8-VSB signal from the primary main transmitter

$\beta$ = amplitude of booster 8-VSB signal

$S_{booster}(t-\tau) = S_{primary}(t-\tau)$ = 8-VSB signal from the on-channel booster output with a time delay, $\tau$

In the above, the critical parameter is that the time delay, $\tau$, through the booster has to be minimized. This will allow that the consumer receiver can take advantage of the primary and the booster output signal. In fact, this delay through the booster must be much smaller than the equalizer span in a consumer 8-VSB receiver such that the received signal can be properly equalized. Such equalization in the receiver has the effect of improving SNR and improving reception at a consumer location.

In equation (2), typical real-world scenario will dictate that $\beta > \alpha$. This means, then, the primary signal will appear to the consumer receiver as a pre-echo rather than a post-echo signal. The equalizer, as part of a demodulation process in a consumer receiver, will train on the larger signal from the booster and will try to equalize out the primary signal. Thus, the delay through the Digital On-Channel Booster system must be minimized for a proper operation of the consumer receivers.

In a Digital On-Channel Booster system, a digital demodulator is employed to minimize the I.F. band-pass filter effects. Typical configuration of a Digital On-Channel Booster system includes a digital demodulator and generates a digital base-band signal. Using a digital matched filter to maximize the received SNR, this typically causes time delay of about 10uSec or more. A further delay is introduced if Reed-Solomon Decoding, De-interleaving, and Trellis Decoding are implemented. Once the signal is taken down to a base-band digital signal, it can be remodulated to an 8-VSB signal and retransmitted with rejection of the adjacent channels.

As for the remodulation of the 8-VSB signal, it will include a digital modulation filter that requires about 20uSec of delay. If full encoding of Reed-Solomon, Interleaver, and Trellis Encoders are implemented, it will cause even longer delay through the remodulation process. However, the full encoding of Reed-Solomon, Interleaver, and Trellis Encoder, is not necessary as relatively high SNR is expected at the input of the Digital On-Channel Booster.

The Digital On-Channel Booster will also have a rejection capability of the co-channel interference and rejection of multipath and noise errors. However, such digital demod-remod technology usually suffers from an inherent delay such that, by the time the remodulated 8-VSB signal is received by a consumer receiver, it can be beyond its equalizer capability and also appear as a digital noise.

Thus, an ideal solution is to provide an on-channel 8-VSB booster signal with a minimized delay.

**A Reduced Delay 8-VSB Digital On-Channel Booster**

In this concept, as shown in Figure 4, an 8-VSB signal is demodulated and remodulated to generate an 8-VSB signal with a minimized delay.

This system does not require signal modifications like “watermark” on the 8-VSB carrier, [2],[3],[5]. It is applicable and compatible with present 8-VSB transmitters and consumer 8-VSB receivers already deployed in the field today.

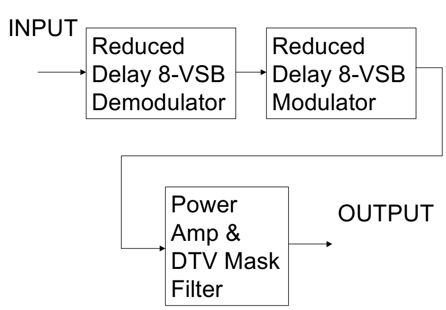


Figure 4 Digital On-Channel Booster

For the reduced delay demodulator, [7], as seen in Figure 5, the 8-VSB signal is down-converted to an I.F. signal. After a suitable I.F. band-pass filtering, a short N-tap equalizer is used to make an approximated matched filter to demodulate the 8-VSB carrier. As for implementation, this technique can be realized either in an analog or a digital domain. However, with advancement of analog-to-digital converter and Digital Signal Processing (DSP) technologies today, the entire or subsections of the process is easily implemented with digital implementation methods.

In this technique, typical long delay associated with a digitally implemented matched filter is reduced to a short delay approximated matched filter. An advantage of combining an analog band-pass filter with a short N-tap Tap-Delay Line filter is a reduced delay throughput while giving the demodulator a matched filter performance in order to maximize the 8-VSB signal SNR. Such design can also equalize out the multipath channel effects since the complex equalizer taps, $C_1$ through $C_N$, can be calculated in accordance with a standard equalization techniques, [1]. Note that no Reed-Solomon decoding, no De-interleaving, and no Trellis decoding are implemented as it is expected that a relatively high SNR will be received at the input.

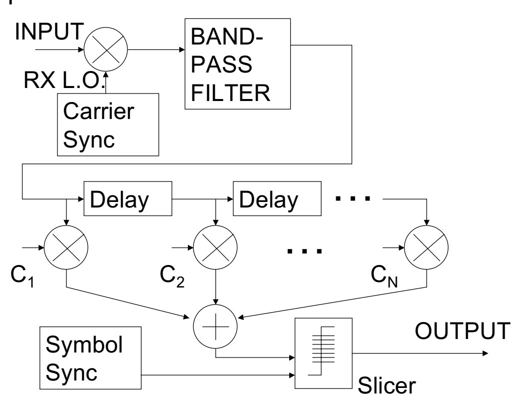


Figure 5 Reduced Delay 8-VSB Demod

In conjunction with the approximated matched filtering, a symbol synchronization and a carrier synchronization must be obtained. This process is required in order to maintain the time and carrier phase synchronization of the Digital On-Channel Booster 8-VSB output signal with the primary 8-VSB transmitter signal.

This is a required signal processing and ensures that the Booster signal will combine with the primary signal for a proper operation in a consumer 8-VSB receiver. For a real implementation, typical configuration requires that the primary 8-VSB transmitter and all of the Digital On-Channel Boosters are locked to a suitable external reference such as that available from a Global Positioning Satellite (GPS) signal, as shown in Figure 6.

With the carrier phase of the on-channel booster locked on to the same GPS signal as that of the primary 8-VSB transmitter, this ensures that the on-channel booster signal is synchronized and allows proper demodulation by the consumer 8-VSB receivers.

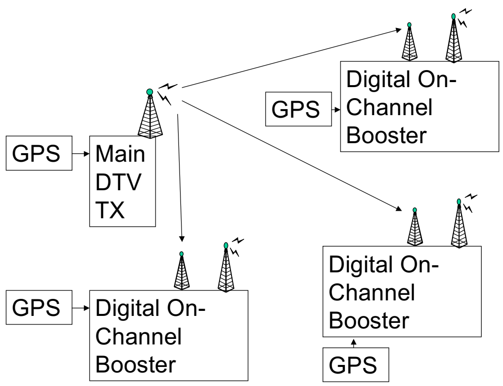


Figure 6 Digital On-Channel Booster System

It is also possible to achieve the same network synchronization without the use of the GPS signal. By using carrier and symbol synchronization circuits, [1], in the Digital On-Channel Booster, a phase and time synchronized 8-VSB signal can be generated at the output of the Digital On-Channel Booster.

Another critical added component of the 8-VSB Digital On-Channel Booster is a low delay modulation system as shown in Figure 7. This also combines an analog filter with an M-tap Tap-Delay-Line filter. This is a pre-correction equalizer in the signal chain. An M-tap pre-correction equalizer is used in combination of a transmit band-pass filter to implement the reduced delay 8-VSB modulation filter. This technique is also realizable using either analog or digital implementation methods.

To generate the complex M-tap modulation filter coefficients, a pre-distortion equalizer technology can be used to generate the output 8-VSB signal. The M-tap pre-distortion equalizer linearizes a group delay and a magnitude distortion typically present in the output analog filter. This method has a capability to generate the 8-VSB signal with a high output SNR, e.g., 35-40 dB. The control of the taps can be implemented with fixed or an automatic methods. For a fixed tap control, the taps $J_1$ through $J_M$ are calculated a-priori using an external test equipment and loaded into tap-delay-line filter. For automatic control, the tap values are self-calculated using a standard equalization techniques, [1]. The analog filter is also made with steep skirts such that FCC DTV mask filter response can be obtained as well.

The length of the tap-delay line filter can be varied depending upon system requirement. If the output SNR is not important, then $J_1$ is set to a constant non-zero number and the rest of the taps are set to zero. This will actually reduce the time delay through the system. In most cases, the output SNR of 27dB is typically desired. So, a pre-correction technique is used to implement the Tap-Delay Line filter.

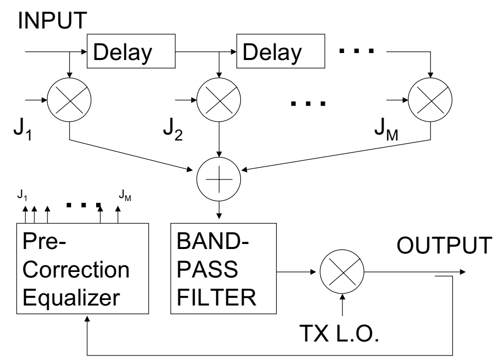


Figure 7 Reduced Delay 8-VSB Modulator

Note that the reduced 8-VSB Modulation filter does not include an RS Encoder, an Interleaver or a Trellis Encoder. This is not necessary as the Digital On-Channel Booster is expected to see a relatively high SNR at its receiver input. A simple hard or soft symbol detection of the 8 symbols is all that is needed to clean up and give some level of rejection of noise, as shown in Figure 5.

The output of the reduced 8-VSB modulation filter is up-converted to an RF channel. The same receive L.O. can be used as the transmit L.O., and is locked to the GPS signal to maintain carrier synchronization.

With combination of the reduced 8-VSB demodulator and reduced 8-VSB modulator, this technique can be made to have a throughput delay of less than a few microseconds through the system. It is also feasible to make this delay programmable in the field such that optimum system performance can be obtained.

Using techniques outlined in this section, an exact replica of the main 8-VSB transmitter signal can be regenerated while minimizing a time delay though the 8-VSB Digital On-Channel Booster.

**Conclusions**

In this paper, issues related to a DTV on-channel booster are discussed and a new method to maintain synchronization, allow low delay throughput, and create an exact replica of the primary transmitter 8-VSB signal is introduced. The concept allows to be implemented with transmitters already deployed in the field today. No watermarking in the transmitter is needed either. It is also compatible and causes no performance issues with consumer 8-VSB receivers.

This method is also attractive for a low cost implementation due to digital realization. A method is described to reduce the throughput delay by combining a receive Tap-Delay Line filter with an analog filter to make an approximated received matched filter. A GPS signal is used to synchronize the carrier frequencies throughout the network.

As for a reduced 8-VSB modulation filter, the use of another tap-delay-line filter in a pre-distortion equalizer configuration and addition of an analog transmit 8-VSB modulation filter completes the system. No full encoding of RS encoder, interleaver and Trellis encoder is needed since the received SNR is relatively high. A digital soft or hard decision method is employed to maintain rejection against noise errors.

In an ever increasingly crowded UHF spectrum, there is a strong motivation for efficient use of the RF spectrum. A Digital On-Channel Booster system for 8-VSB is feasible and allows such efficient use of the RF spectrum.

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