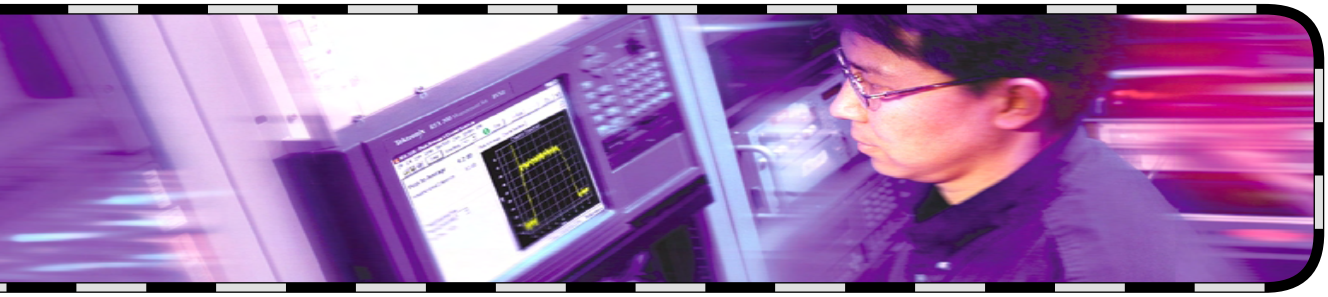
Fundamentals of 8VSB



8VSB Primer

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In December 1997, the FCC formalized the use of the ATSC standard A/53 [1] for broadcast transmission in the United States. Within this standard, 8VSB is defined as the terrestrial transmission format. 8VSB is a Vestigial Sideband digital modulation system. Using eight discreet amplitude modulation levels, these eight modulation levels are assigned eight different binary numbers, or symbol values, to convey the MPEG compressed transport stream. The MPEG-2 transport stream provides a methodology for the packetization of compressed video, audio and data packets. [2]

The 8VSB transmission system supports a payload data rate of 19.28 Mb/s in a 6 MHz channel. The input to the transmission subsystem from the transport subsystem is a 19.39 Mb/s serial data stream comprised of 188-byte MPEG-2 compatible data packets. This 188-byte packet has an initial sync byte (47hex) followed by 187 bytes of payload data.

The diagram in Figure 1 shows the basic functions of an 8VSB transmitter. An MPEG-2 transport stream conforming to SMPTE 310 [3] standard is applied to a synchronizer, which locks to the data rate of the transport stream using the sync byte to identify the start of each 188 byte transport stream packet. The MPEG-2 sync byte is then removed, producing 187-byte payload data packets. The sync byte will be replaced by the segment sync after the forward error correction.

The 187-byte data packets must be randomized with a pseudo-random bitstream. This ensures a noise-like spectrum and reduces interference to NTSC channels. This is achieved by taking each byte of data and changing its value using a known pattern generated from a pseudo-random binary sequence (PRBS). The PRBS is reversed in the receiver to recover the original data. Randomizing the data helps in the recovery of segment and field syncs, which are added later in the process and are not part of this process, enabling the receiver to distinguish these events from the randomized data. If the input signal were lost, this would result in a long string of “1s” or “0s”. A repeating pattern would cause the RF energy to be unevenly distributed through the channel. This uneven distribution could produce beat patterns within an NTSC receiver if DTV to NTSC interference were experienced.

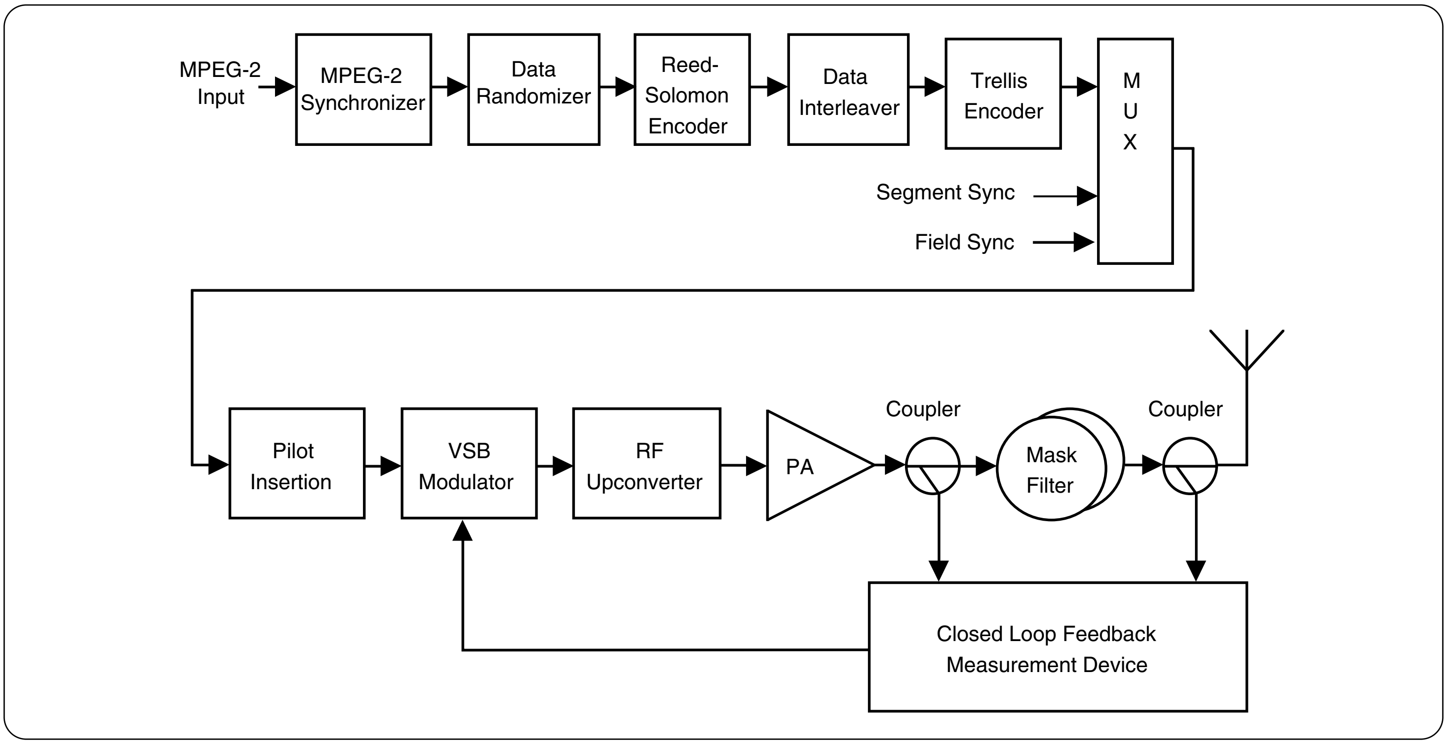


Figure 1. *Block Diagram of 8VSB Transmitter.*

Forward error correction is applied to the data to add extra information which describes the structure of the original data stream. The system can then use this information to correct for bit errors that may have occurred during transmission.

The Reed-Solomon encoder operates byte-wise on the 187 bytes of the randomized MPEG-2 packet. It performs a mathematical manipulation on the data to produce a 20-byte block of information describing the original 187 bytes of data. These 20 bytes are added to the end of the 187 bytes to produce a total Reed-Solomon block size of 207 bytes.

Using the equation:

$$t = (n - k) / 2$$

Where: n = total block size = 207
k = original data size = 187
t = number of bytes which can be corrected = 10

Therefore, the Reed-Solomon encoder can handle short “bursty” errors of no more than 10 bytes per packet. If more than 10 error bytes occur within the packet, the data must be discarded.

Noise bursts may be longer than the Reed-Solomon coding can handle. To further protect the data, interleaving is performed. Data interleaving shuffles the sequential order of the data over time (see Figure 2).

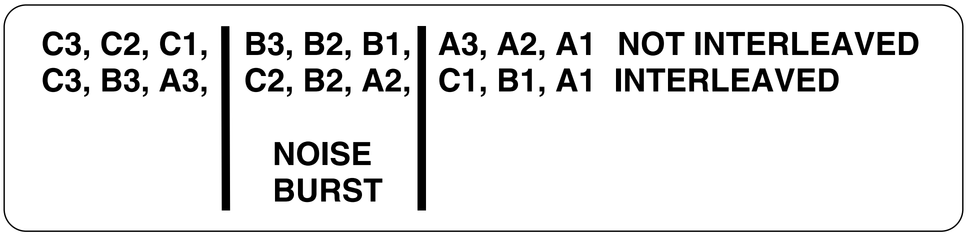


Figure 2. *Simple example of three-segment data interleaver.*

In this simple example, a noise burst that obliterates all three ‘B’ data values of a non-interleaved signal would prevent recovery of the data by a Reed-Solomon decoder. By interleaving the data, the same noise burst obliterates only a single value of A, B and C, leaving enough data values for the Reed-Solomon decoder to determine the correct values of the missing data. In 8VSB, the data interleaver is much more complex, operating to a depth of 52 segments making it possible to handle noise bursts up to 193 µs.

Additional error correction is added by means of Trellis-Coded Modulation. Trellis coding divides a byte into 2-bit words and mathematically generates a 3-bit code word as shown in Figure 3. Adding one additional bit of information to the original two bits of information provides a history of the change in data values from the previous value to the current one. The Trellis coding is therefore a 2/3-convolution coder and produces eight possible states that become the eight levels (–7 to +7) in 8VSB. The Trellis decoder (Viterbi) in a receiver uses the three bits to reconstruct the path of

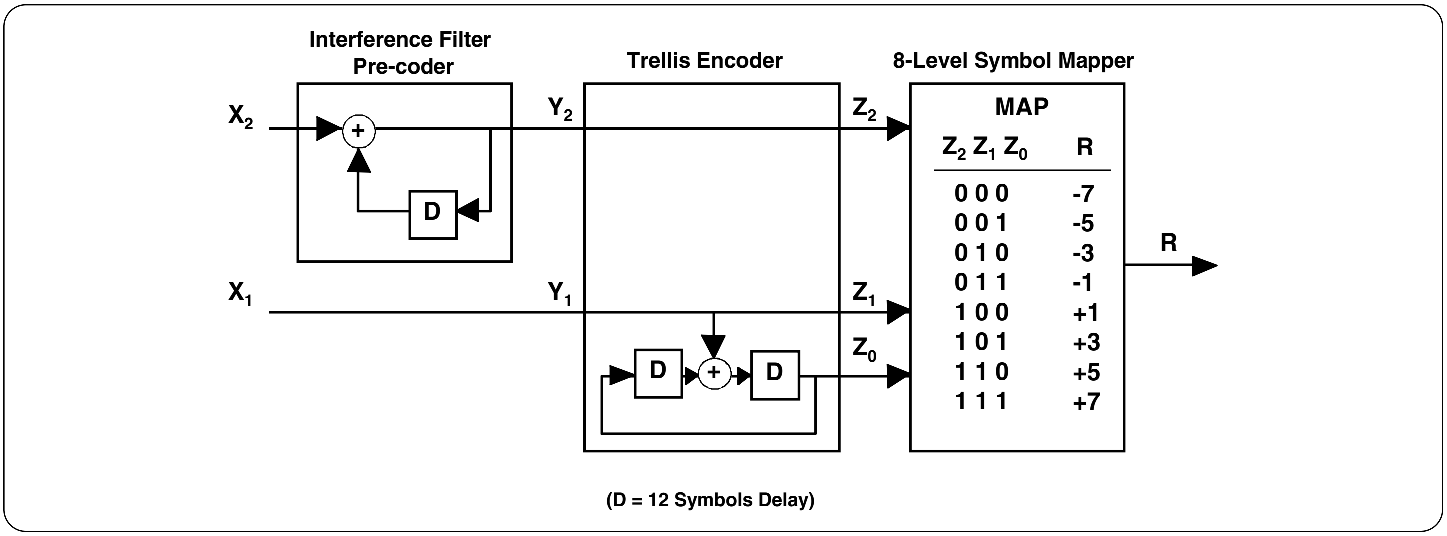


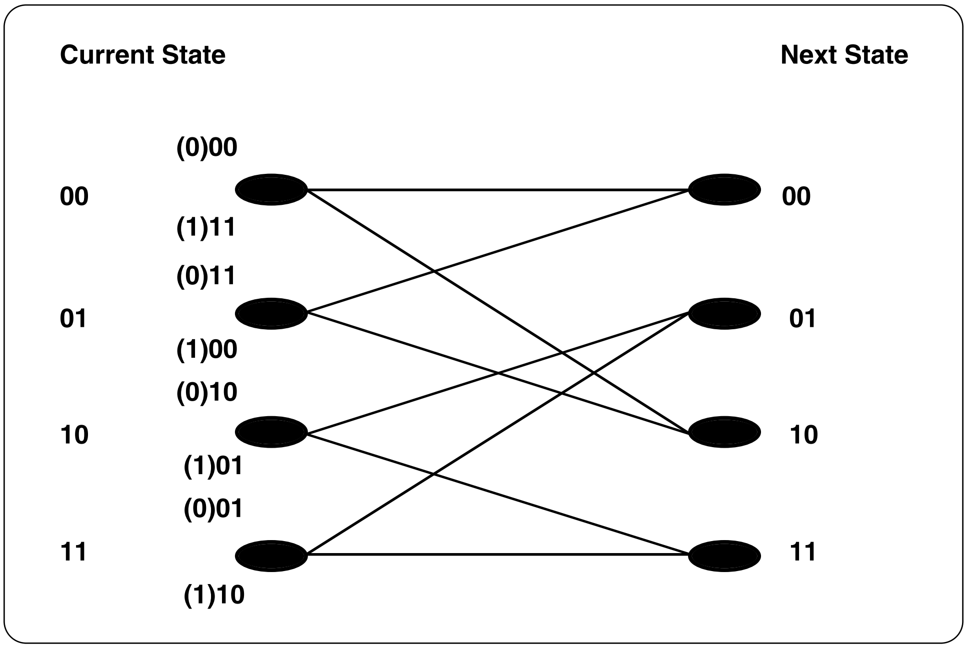
Figure 3. *8VSB trellis encoder, precoder, and symbol mapper.*

the data stream from one 2-bit word to the next. The Trellis and Viterbi coding scheme is very effective in managing white noise.

In any one interval, however, only four of the states are valid, depending on the previous interval. If the valid state changes are diagrammed, the result resembles a garden trellis, hence the name Trellis Encoding or Trellis-Coded Modulation (see Figure 4).

This completes the Forward Error Correction stages within the digital modulation process. The three bits have eight possible values; within the 8VSB system, each of the values ‘000’ to ‘111’ can be represented by a symbol level –7 to +7. A symbol is a discrete level that represents a digital word. The 207 bytes of data are therefore represented by 828 symbol values (see Figure 5).

The next stage of the system provides synchronizing signals that can help the decoder lock-to-signal and allow recovery of the data. Segment sync and field syncs are multiplexed into the data stream before each data packet of 828 symbols. The segment sync replaces the original MPEG-2 sync byte and consists of a two-level signal that forms a positive-negative-positive pulse between +5 and –5 with a duration of four symbols. Each seg-



▶ ***Figure 4.*** *A simplified Trellis diagram showing allowed state changes for a half-rate coder.*

–7 = 000
–5 = 001
–3 = 010
–1 = 011
+1 = 100
+3 = 101
+5 = 110
+7 = 111

8VSB Symbol values before pilot insertion

Calculation of Symbol Rate:
Sr (MHz) = 4.5 / 286 x 684 = 10.76 MHz

Frequency of a Data Segment:
f_{seq} = Sr / 832 = 12.94 x 10^3 data segments/s

Data Frame Rate:
f_{frame} = f_{seg} / 620 = 20.66 frames/s

Total Number of Bits:
187 data + 20 RS = 207 byte packet = 1656 bits

Trellis coding requires:
3 / 2 x 1656 bits = 2484 bits

▶ ***Figure 5.*** *Calculation of symbol rate.*

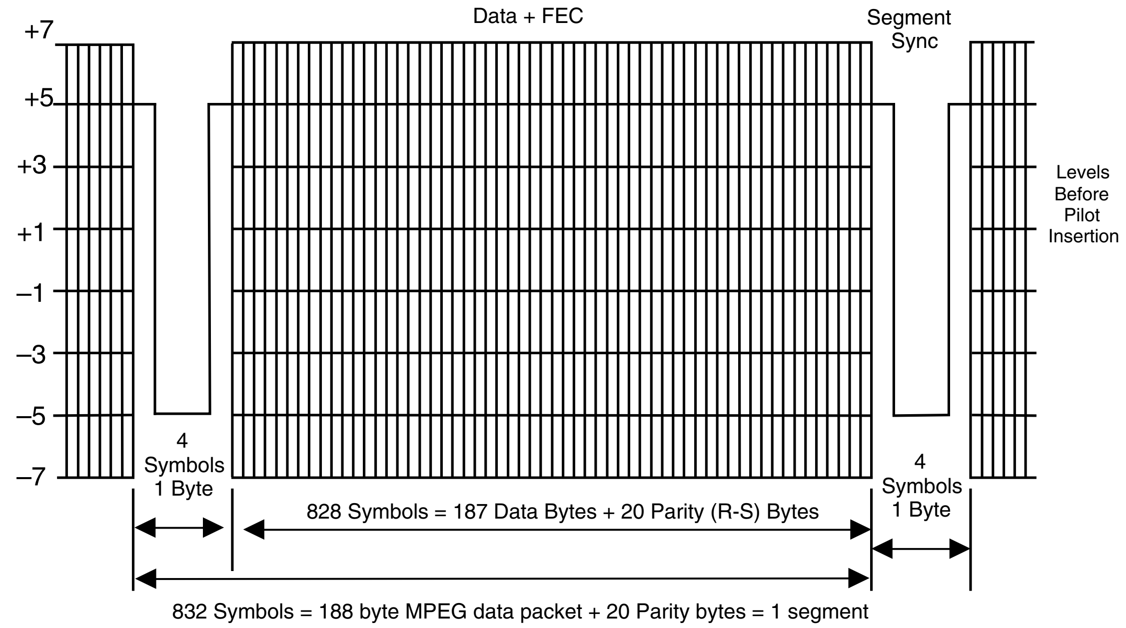


Figure 6. *A Single segment of the 8VSB digital baseband signal.*

ment has a duration of 77.3 µs and consists of a total of 832 symbols (see Figure 6).

A transmission data frame occurs every 616 segments (48.4 ms). The data frame is spilt into two fields, which occur every 313 segments (24.2 ms). The first segment of each field contains a field sync (see Figure 7).

The field sync carries a training reference signal for the receiver's equalizer and consists of the four symbols of segment sync followed by 511 reference symbols. In the receiver, these are used for adjusting the long equalizer taps. After the 511 reference symbols for the long equalizer taps, there are three sets of 63 reference symbols for adjusting the short equalizer

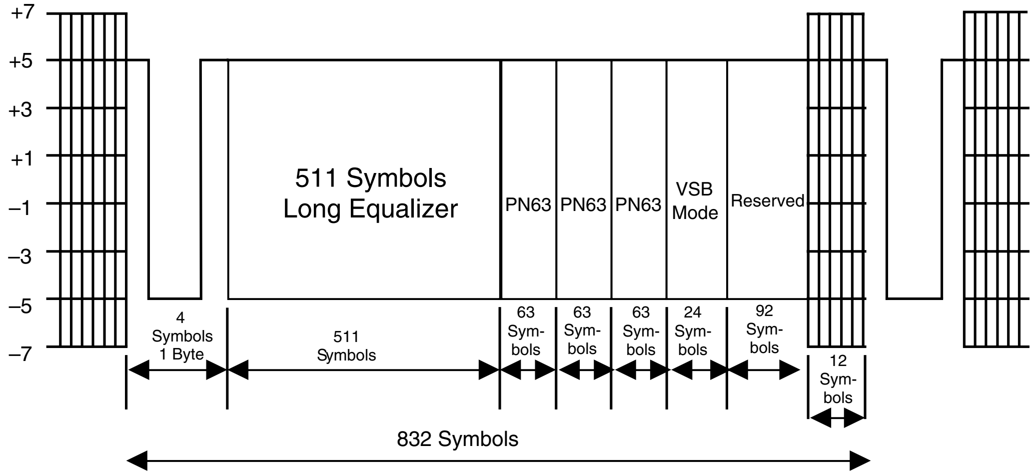


Figure 7. *A segment of a field sync of the 8VSB digital baseband signal.*

taps. Next are 24 symbols for VSB level ID identifying whether 8 or 16 VSB is being used, 92 symbols are reserved for future use, and 12 symbols are repeated from the previous segment to allow the receiver to continue synchronization of the data (Figure 8).

A small pilot carrier is added to the data signal. The frequency of the pilot is the same as the suppressed-carrier frequency and is generated by adding a 1.25 V DC level to every symbol (data and sync). The pilot is 0.3 dB of average signal power. The 8VSB signal is transmitted as a single sideband suppressed carrier signal. The digital representation of the signal is split in two and passed through a root-raised cosine filter and converted to analog signal by high-speed Digital-to-Analog converters. The channel occupancy is shown in Figure 9 with the suppressed carrier frequency 310 kHz from the lower-band edge; the roll-off at the band edge is due to the root-raised cosine response. The analog signals are fed to two mixers, which are phase shifted by 90°. The output is a 44 MHz IF signal, upper sideband only, with raised-cosine response. At this point the signal can be upconverted to the required channel frequency, sent to the Power Amplifier stages, and broadcast. A measurement device attached to the output stages can provide information back to the VSB modulator to pre-correct for errors in the transmission process.

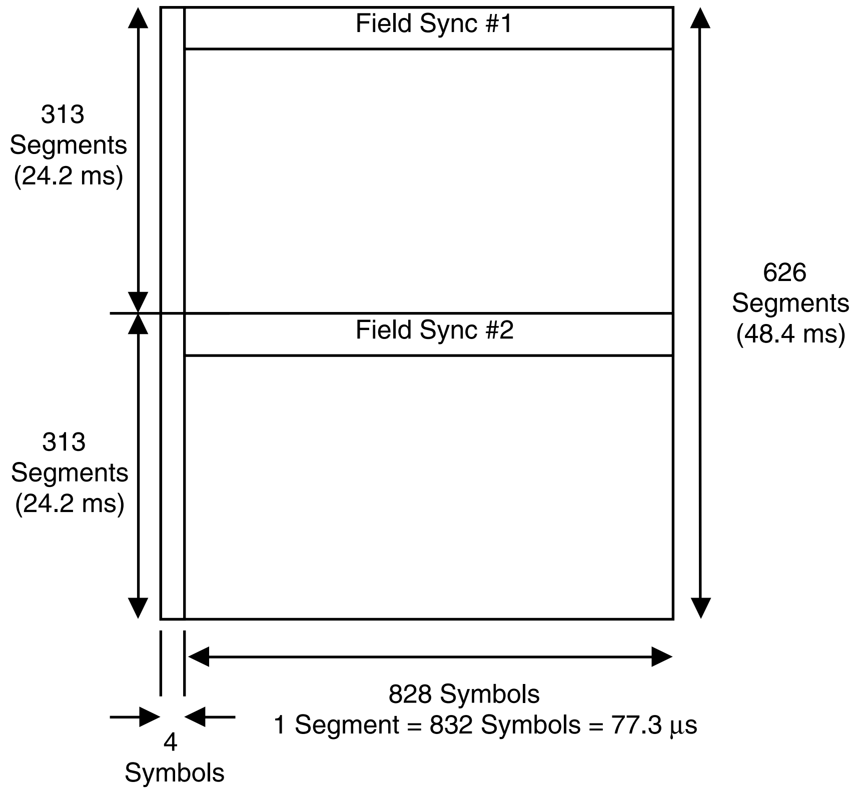


Figure 8. *Frame structure of 8VSB.*

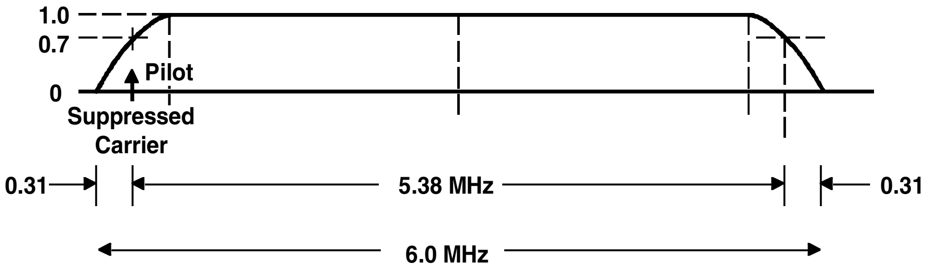


Figure 9. *VSB channel occupancy.*

Reception and Decoding

The first process in the receiver is to look for the pilot and phase lock the incoming signal. Once lock is achieved, the decoder locates the segment sync, which is very distinct from the rest of the random data and obtains a data lock to the symbol frequency. Even impaired signals can be phase locked and the segment sync located. Next, the training sequence must be located because it provides the information needed to identify the VSB level and set the equalizer taps to correct for unflatness in the noise-like spectrum of the channel allowing the conditioned signal to be decoded into the 19.39 Mb/s data stream. Viterbi decoding in the receiver works in conjunction with the Trellis coding in the transmitter to optimize performance in the presence of white noise. Viterbi decoding looks at the incoming data over time and picks the most likely positions in the trellis. This is similar to a musician listening to a few bars of music. The musician can detect a sour note within the piece of music and then determine the correct note that should have been played.

Digital reception produces a near perfect reproduction of the original picture and sound or no picture at all. Analog signals degrade gracefully and the human eye is able to cope with some of these errors and tune out some of these defects, particularly when it is the last quarter of the football game. A digital system is a ‘1’ or ‘0’ – either On or Off – and are therefore subject to a “cliff effect.” Viewers, who have been tolerating poor picture quality because of inadequate antenna, low signal level or noisy reception, may find they cannot receive a digital signal. Viewers living in the Grade B contour and fringe areas may find reception intermittent. It is therefore critical to monitor the performance of the transmitter because degradation in performance could significantly reduce the coverage area.

References

1. Advanced Television Systems Committee, ATSC Digital Television Standard Document A/53, 16 Sept. 1995.
2. ISO/IEC DIS 13818-1 MPEG-2 Systems Layer (Moving Picture Experts Group).
3. Society of Motion Picture and Television Engineers SMPTE standard 310M Synchronous Serial Interface for MPEG-2 Digital Transport Stream, 29 Sept 1998.

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