Questions Before Quiz

COFDM

Coded orthogonal frequency division multiplexing.

What is a slice?

A set of macroblocks in a line.

Containment Hierarchy in MPEG Video

Blocks don't have headers. Everything above a block has headers. Macroblock, slice, picture, group of picture, sequence, elementary stream, program stream, transmission/transport stream.

Multiplex audio into the transport stream (see later in today's lecture).

ATSC Pilot

Always got some tone there, the difference between the carrier and the receiver's local oscillator. Offset slightly from the carrier, should get a tone that is the difference between the offset and the carrier. That's what a pilot is. It allows the receiver to lock into the signal. It is a beat frequency.

Quiz

8-VSB Exciter

Input 19.39 Mbits/sec. To: frame synchronizer, data randomizer, reed-solomon encoder, data interleaver, trellis encoder, sync insertion (adds segment sync and field sync), pilot insertion, 8-VSB modulator, analog upconversion, to 8-VSB RF output.

Why are we doing all of this stuff to this poor signal? Make efficient use of the available bandwidth.

Data Synchronization

First thing 8-VSB exciter does upon receiving MPEG-2 datapackets is to synchronize its own internal circuits to the incoming signal. Before any signal processing can occur, the 8-VSB exciter must correctly identify the starting and ending points of each MPEG-2 data packet. Accomplished using MPEG-2 sync byte. MPEG-2 packets have first byte being sync byte. Sync byte will be discarded; it will ultimately be replaced by the ATSC segment sync in a later stage of processing.

Data Randomizer

With exception of segment and field syncs, the 8-VSB bit stream must have a completely random, noise-like nature (pink noise – constant energy distribution across spectrum). This is because the transmitted signal frequency response must have a flat noise-like spectrum in order to use the allotted RF channel space with maximum efficiency. If the data contained repetitious patterns, the recurring rhythm of these patterns would cause the RF energy content of the transmitted signal to lump together at certain discrete points in the frequency spectrum, thereby leaving holes at other frequencies.

This implies that certain parts of the 6 MHz channel would be overused, while other parts would be underused. Plus, the large concentrations of RF energy at certain modulating frequencies would be more likely to create discernible beat patterns in an NTSC television set, if DTV-to-NTSC interference were experienced. Horror stories when DTV first started broadcasting (6-8 years ago). Medical equipment in hospitals was failing; somebody attributed this to DTV. Broadcast on same frequency allocation as UHF NTSC channels.

In the data randomizer, each byte value is changed according to a known pattern of pseudo-random number generation. This process is reversed in the DTV receiver in order to recover the proper data values.

Digital radio does the same thing. Randomize the digits and the signal looks like noise. Can tune channels on FM on an analog FM radio and hear something that sounds not quite right.

Reed-Solomon Encoding

Reed Solomon encoding is a Forward Error Correction (FEC) scheme applied to the incoming data stream. Forward error correction is a general term used to describe a variety of techniques that can be used to correct bit errors that occur during transmission. Atmospheric noise, multipath propagation, signal fades, and transmitter non-linearities may all create received bit errors. Forward error correction can detect and correct these errors, up to a reasonable limit. The Reed-Solomon encoder takes all 187 bytes (sync removed) of an incoming MPEG-2 data packet and mathematically manipulates them as a block to create a sort of “digital ID tag” of the block contents. This ID tag occupies 20 additional bytes which are then tacked onto the tail end of the original 187-byte packet by the encoder. These 20 bytes are known as Reed-Solomon parity bytes.

The DTV receiver compares the receive 187-byte clock to the 20 parity bytes to determine if the validity of the recovered data. If errors detected, receiver determines that the ID tag no longer corresponds to the packet contents and searches for a similar packet that most closely matches the received tag.

Example of eyewitness mistaking the license plate of a bank robber; no match between car description and reported license plate. Look for similar cars, similar years, similar license plate in police database.

The Reed-Solomon decoder in the DTV receiver performs a similar operation by comparing parity bytes to determine the most likely transmitted packet.

Unfortunately, this type of error correction has its limits. The greater discrepancy between Reed-Solomon bytes and received packet, the greater chance of error in matching correct ID tag to correct packet. At some point ambiguity becomes too great to draw a reasonable conclusion as to the correct data.

Reed-Solomon coding scheme used in DTV can correct up to 10 byte errors per packet. If too many byte errors are present in a given packet, receiver can no longer match parity tag to any packet with a sufficient level of certainty. The entire MPEG-2 packet must be discarded since validity of data can no longer be confirmed.

Data Interleaver

Scrambles sequential order of data stream and disperses MPEG-2 packet data throughout type (over a range of about 4.5 msec through the use of memory buffers) in order to minimize the transmitted signal's sensitivity to burst-type interference. The data interleaver then assembles new data packets incorporating tiny fragments from many different MPEG-2 (pre-interleaved) packets. These reconstituted data packets are the same length as the original MPEG-2 packets: 207 bytes (after Reed-Solomon coding).

What is this equivalent to in something we've talked about? Steve had an example but needs to be sure about it.

This is equivalent to spreading all of your eggs (bytes) over many different (time) baskets. If a noise burst punches a hole in the signal during propagation and one basket is lost (i.e., several milliseconds), many different MPEG-2 packets lose one egg instead of one MPEG-2 packet losing all its eggs.

This is known as ***time diversity***.

If each packet only loses a tiny number of bytes, R-S decoder in DTV receiver can correct it and recover data.

Data interleaving done according to known pattern; process reversed in receiver to recover proper data order.

Trellis Encoder

Yet another form of forward error correction. Unlike R-S coding, which treated packet as a block (a **block** code), trellis coding is an evolving code that tracks the progressing stream of bits as it develops through time. Called a **convolutional** code.

For trellis coding, each 8-bit byte is split up into a stream of four, 2-bit words. Each 2-bit word that arrives is compared to the past history of previous 2-bit words. A 3-bit binary code is mathematically generated to describe the transition from the previous 2-bit word to the current one. These 3-bit code3s are substituted for the original 2-bit words and transmitted over the air as the 8 level symbols of 8-VSB (2 to the 3 power). For every 2 bits going into encoder, 3 bits come out. For this reason, the trellis coder in the 8-VSB system is said to be a 2/3-rate coder.

The trellis decoder in receiver uses received 3-bit transition code to reconstruct the evolution of the data stream from one 2-bit word to the next. In this way, the trellis coder follows a trail as the signal moves from word to word. The power of trellis coding lies in its ability to track a signal's history through time and discard potentially faulty infomation (errors) based on a signal's past and future behavior.

Oscilloscope Displaying 8-VSB Signal

Shows scope shot of 8 levels in 8-VSB. Diagram 1. This is 8 levels of voltage (amplitude). This is more compression. This is the signal that gets modulated onto the carrier. Called Trellis coded 8-VSB baseband data segment format. What's first step we take to decode this? Demodulate the signal, feed to Trellis decoder, decode down to 2 bits, concatenate the 2-bit sets into the data stream. Called trellis because the levels on the scope look like a trellis that climbing vines climb.

Part of randomization is to avoid having that nasty DC show up again. Diagram 1 has multiple values smeared across each other, like watching time code on the oscilloscope. A single value might look like diagram 2.

Diagram 1 is an actual signal. What do we see about it? Each part of the trellis looks about the same intensity; this is due to randomization. That's what we want: to cover the spectrum efficiently and completely. Having strong amount of error correction here allows receiver to handle being able to differentiate among the 8 voltage levels.

There's a sync pulse every so many microseconds. There are 832 symbols (trellis vertical sections) between sync pulses. 77.3 microsecond segment including sync pulse.

Each vertical trellis section encodes 3 bits, which really encoded 2 bits.

Diagram 3 shows the sync pulse and the 832 symbols between sync pulses. The 8 levels are: -7 -5 -3 -1 1 3 5 7. Sync tip is at -5 and the base is at 5.

Sync and Pilot Insertion

Next step in signal processing chain is insertion of various helper signals that aid DTV receigfverto accurately locate and demodulate the transmitted RF signal. These are the **ATSC pilot**, **segment sync**, and **field sync**.

The pilot and sync signals are inserted after the randomization and error coding stages so as not to destroy the fixed time and amplitude relationships that these signals must possess to be effective. Don't want to randomize sync.

Recovering a clock signal in order to decode a received waveform has always been a tricky proposition in digital RF communications. If we derive the receiver clock from the recovered data, we have a sort of chicken and egg dilemma. The data must be sampled by the receiver clock in order to be accurately recovered. The receiver clock itself must be generated from accurately recovered data. The resulting clocking system quickly crashes when the noise or interference level rises to a point that significant data errors are received.

When NTSC invented need recognized to have powerful sync signal that rose above the rest of the RF modulation envelope. The receiver synchronization circuits could still hone in on the sync pulses and maintain the correct picture framing even if the contents of the picture were a bit snowy. Sync in France is the weakest part of the signal.

NTSC also benefited from a large residual visual carrier (caused by the DC component of the modulating video, which is from sync) that helped TV receiver tuners zero in on the transmitted carrier central frequency.

8-VSB employs a similar strategy of sync pulses and residual carriers that allows the DTV receiver to lock onto the incoming signal and begin decoding even in the presence of heavy ghosting and high noise levels.

The first helper signal is the ATSC pilot. Just before modulation, a small DC shift applied to the 8-level baseband signal (which was previously centered about zero volts with no DC component. (What is a baseband signal? NTSC in the studio, like a color bar signal or camera signal. Not been modulated onto any carrier.)

This causes a small residual carrier to appear at the zero frequency point of the resulting modulated spectrum. This is the ATSC pilot. This gives the RF PLL circuits in the DTV receiver something to lock onto that is independent of the transmitted data. Where else do we use a pilot? Stereo audio on FM. Small signal at 19 kHz amplified and doubled to where L-R is (modulated on 38 kHz carrier). Stereo audio in NTSC TV is two times the line frequency (15734 Hz).

One of Steve's companies where he worked. Pilot on a tape recorder. Lock to vertical sync. Every time head wheel comes around, should be the vertical sync pulse. Can replace vertical sync so can afford to lose it. Precision Echo had a helical scan recorder. Challenge to record 60 MHz (?) sine wave. Recorded 250 Hz pilot along with the signal. Locked position of our head. Pilot tone did interfere with video, but took measures to compensate for this.

Although similar in nature, ATSC pilot much smaller than the NTSC visual carrier, consuming only 0.3 dB or 7 percent of the transmitted power.

The other helper signals are the ATSC segment and field syncs. An ATSC data segment is comprised of 207 bytes of an interleaved data packet. After trellis coding, the 207-byte segment has been stretched out into a a stream of 838 eight-level symbols. The ATSC segment sync is a **four-symbol pulse** that is added to the front of each data segment and replaces the missing first byte (packet sync byte) of the original MPEG-2 data packet. The segment sync appears once every 832 symbols and always takes the form of a positive-negative-positive pulse swinging between the +5 and -5 signal levels. Arranged as Segment Sync (4 symbols), 188 byte (752 symbol) MPEG-2 data packet, 20 bytes (80 symbols) Reed-Solomon. The segment sync is broader than a trellis pulse (four symbols instead of one, but the tip width is less than 4 because the 4 includes the base around the pulse).

Correlation circuits in the 8-VSB receiver home in on the repetitive nature of the segment sync, which is contrasted against the background of pseudo-random data (remember the data randomizer processing stage).

The recovered segment sync is used by the receiver to regenerate the system clock and sample the received signal. Because of their high frequency of repetition, large signal level swing, and extended duration, the segment syncs are easy for the receiver to spot. Consequently, accurate clock recovery can be had at noise and interference levels well above those where data recovery is impossible (up to 0 dB SNR – data recovery requires at least 15 dB SNR).

This robust synchronization system, along with ATSC pilot, allows the DTV receiver to recover lock-up quickly during channel changes and other transient condtions.

An ATSC data segment roughly analogous to an NTSC line. ATSC segment sync somewhat like horizontal sync. Duration and frequencies of repetition are different. ATSC segment sync lasts 0.37 microseconds. NTSC sync lasts 4.7 microseconds. ATSC data segment lasts 77.3 microseconds, an NTSC line 63.6 microseconds.

Careful inspection of numbers involved reveals that ATSC segment somewhat more slender when compared to NTSC counterpart; could do this because today's components can handle narrower sync pulses well unlike decades ago. Done to maximize active data payload and minimize time committed to sync overhead. **313 consecutive data segment s are combined to make a data field**. The field contains the 313 data segments plus a field sync segment.

The ATSC field sync is an entire data segment that is repeated once per field (24.2 milliseconds) and is roughly analogous to the NTSC vertical interval. ATSC field sync has known data symbol pattern of positive-negative pulses and is used by the receiver ot eliminate signal ghosts caused by poor reception. This is done by comparing the received field sync with errors against the known field sync sequence before transmission. The resulting error vectors are used to adjust the taps of the receiver ghost canceling equalizer. Like segment syncs, the large signal level swing and repetitive nature of field syncs allow them to be successfully recovered at very high noise and interference levels (up to 0 dB SNR).

At end of each field sync segment, the last 12 symbols from last data segment are repeated in order to restart trellis coder in the receiver. The robustness of the segment and field syncs permits accurate clock recovery and ghost canceling operation in the 8-VSB receiver, even when the active data payload is completely corrupted by poor reception conditions. This allows the adaptive ghost-canceling equalizer to hunt around in the mud and recover an usable signal before the data payload has been successfully decoded, thus eliminating the chicken and egg dilemma described earlier.

Look on Internet for all this stuff we have talked about: 8-VSB, exciter, how 8-VSB generated, coding, error corrections, sync pulses.