VSB TRANSMISSION SYSTEM: BROADCAST AND MICROWAVE APPLICATIONS

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1. ABSTRACT

The vestigial sideband (VSB) digital transmission system has been developed for terrestrial, MMDS, and cable television broadcasting in the United States. It was thoroughly evaluated by the FCC's Advisory Committee on Advanced Television Service (ACATS), and on December 24, 1996, this system was adopted as the new digital terrestrial standard for the United States [1,2,3,5,6]. A family of compatible VSB standards suitable for many applications, including microwave, is based on the same rugged signal features that support operation in the difficult terrestrial environment.

2. VSB SYSTEM DESCRIPTION

The spectrum of current analog NTSC vestigial-sideband television has three carriers (visual, chroma, aural), which carry most of the energy in the 6 MHz channel. The digital VSB spectrum, also contained in a 6 MHz channel, is flat throughout most of the band due to the noise-like attributes of randomized data.

The measurement of signal level (power) is different for NTSC and DTV. The NTSC signal is measured as average power during peak sync. The DTV signal is random in nature and has a stable average power, which can be measured and specified [6]. Peaks of the transmitted DTV signal are random, with the highest peaks occurring least frequently. Typically, 99.9% of the VSB signal peaks are within 6.3 dB of the average signal power.

The VSB signal includes a low-level pilot which adds only 0.3 dB to the total signal power. However, it aids carrier recovery independently of data, reduces receiver implementation loss, and provides reliable carrier recovery down to S/N ratios of 0 dB, which is well below (≥10 dB) data error threshold.

In general, VSB may be transmitted in five different modes (2, 4, 8, 8-trellis, and 16), with the data rate dependent upon the number of discrete levels and whether trellis coding is used. The FCC standardized two of these five modes: 19.3 Mbit/sec trellis-coded 8-VSB for terrestrial DTV broadcasting, and 38.6 Mbit/sec 16-VSB (no trellis) for carrying two 19.3 Mb/s HDTV signals in one 6 MHz channel on cable systems.

The data signal is broken into 832-symbol segments, including a 4-symbol, two-level data segment synchronizing signal (sync). The use of data segment syncs in the transmission system does not reduce the data efficiency since they replace the required MPEG-2 packet sync bytes (47 hex) in the transmitter. Syncs can be easily extracted from the data through correlation methods, and can provide reliable synchronization down to S/N ratios of 0 dB. The symbol rate for all VSB modes is 10.762 MHz. The segment is compatible with the 188-byte MPEG-2 transport data packet used internationally (including the U.S. DTV standard). Each segment contains an additional twenty Reed-Solomon parity bytes for forward error correction (FEC) of up to 10 byte errors/segment.

Data segments are further grouped into frames. Each frame contains one frame sync, which is one segment long (832 symbols) and repeats every 313 segments. The data efficiency is reduced by only 0.32% (1/313) due to the insertion of data frame syncs. The data frame sync segment carries a known two-level reference training signal for the receiver equalizer, which allows stable operation regardless of data eye closure, and is a means of determining received signal conditions (such as S/N ratio).

The complete VSB data frame, which includes data, FEC, and syncs gives an overall data efficiency of 90%. All VSB modes use identical pilot and synchronizing signals and (207, 187) RS coding for compatibility.

3. VSB CHARACTERISTICS

Two VSB modes are defined in the Grand Alliance transmission system: trellis-coded 8-VSB for terrestrial, and 16-VSB for cable. **Table 1** contains the characteristics of all five of the ITU-T (Amended J.83 [1997]) VSB modes. They share many of the same fundamental characteristics, such as channel and excess bandwidth, symbol rate, field and segment syncs, segment length and duration, and pilot power.

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Parameters	2-VSB	4-VSB	8-VSB	16-VSB	8T-VSB	Units
Bandwidth Efficiency	1	2	3	4	3	Bits/symbol
Payload Data Rate	9.6	19.3	28.9	38.6	19.3	Mbits/sec
S/N @ Threshold	9.8	16.1	22.3	28.5	15.0	dB
Phase Noise Threshold @ 20 kHz	-68	-73	-78	-83	-78	dBc/Hz
Impulse Noise Threshold	386	193	128	96	193	usec

Table 1 Characteristics of the five ITU-T (Amended J.83 [1997]) VSB modes

The S/N thresholds in table 1 correspond to 2.5 segment errors/second. This corresponds to the threshold of visibility in a digital television receiver that does not use error masking (concealment).

An additional feature of the 8-VSB terrestrial mode not discussed above is the NTSC rejection comb filter. In the 8-VSB-T mode, digital pre-coding allows optional use of the NTSC rejection filter at the receiver. With the comb filter, the 8-VSB signal can operate with NTSC co-channel D/U ratios of +2 dB or better. The comb filter can be switched on or off seamlessly in the receiver depending on local signal requirements.

4. VSB MICROWAVE SYSTEMS

Two VSB modes are appropriate for MMDS operation: 4-VSB and 8-VSB. 4-VSB (19.3 Mbps) can generally accommodate 6 movies, 4 live shows, or 3 live sports shows per 6 MHz channel. 8-VSB (29 Mbps) can accommodate 9 movies, 6 live channels, or 4 sports programs.

MMDS lab and field tests using VSB were performed in conjunction with the Wireless Cable Digital Alliance [9].

4.1.1 MMDS Lab Tests

Laboratory testing was performed using 4-VSB with MMDS hardware. Modern 10 and 50 Watt solid state transmitters were used, operating class A. Adjacent channel energy spillage (band edge) was typically near 50 dB down from band center energy at the same spectral density. This is thoroughly adequate for operation adjacent to an NTSC signal.

The phase noise of some older in-service transmitters was on the high side, typically -85 dBc/Hz at 20 KHz from the local oscillator carrier. Consideration should be given to upgrading the transmitter phase noise value to better than -95 dBc/Hz at 20 KHz for digital transmission systems in order to obtain the best performance in the field, especially if older downconverters with poor phase noise are prevalent in the system.

Twenty-two downconverters from three different manufacturers were randomly selected and measured in the lab. The worst group of converters produced a 1.5 dB impact on white noise threshold, while the best showed less than 0.5 dB degradation. The limiting factor was the phase noise of the downconverter's local oscillator. All of these units are usable with 4-VSB, although it would be desirable to improve the poorer ones to gain back the 1.5 dB penalty.

Currently, transmitter and downconverter manufacturers are selling "digital ready" units, with phase noise numbers in the low to mid nineties (at 20 KHz offset). These units remove the phase noise concern completely for new builds, and easily allow 8-VSB to be transmitted.

4.1.2 MMDS Field Tests

The 4-VSB system has been tested in three cities over a three month period: Chicago, Colorado Springs, and Orlando. Digital VSB is typically transmitted at about 12.5 watts transmitter power output. Adjacent channel spillage is about 48 dB down at band edge, with no interference into adjacent NTSC signals.

A major item recorded in field tests is the margin, that is, the difference between the received signal level and the point of failure. The Chicago field test margins ranged between 18-41 dB, depending on the site conditions. Most of the variation was due to varying foliage throughout the area. These figures indicate an 18 dB improvement over the reception of analog NTSC. Experiments with reception through foliage showed attenuations of 3 to15 dB.

Another major item studied was multipath conditions and the operation of the equalizer. The equalizer tap energy (defined as the ratio of energy in all the taps other than the main tap to the main tap energy) is recorded to indicate reception conditions. In the field tests, no cases of extreme long-delay multipath were encountered, despite attempts to find some in difficult locations.

In Orlando, a unique situation was encountered because the northern and southern parts of the area are transmitted on different polarizations. At one site where the signals overlap, the received signal showed a severe (12 dB) tilt across the band. Reception was still stable, with over 8 dB margin

One location had strong adjacent NTSC channels present, 20 dB above the VSB signal, This site still had over 11 dB of margin.

5. COMPARISON OF VSB WITH COFDM

Although the VSB system is not designed to handle zero-dB ghosts, it approaches that performance in many practical cases, and does so without an excessive power penalty. For comparison, we take figures from reference [11], which studied both theoretical and experimental performance of DVB-T transmission. The data we extract below is for the DVB-T option closest to VSB in bit rate: 8 k system, 64QAM, Viterbi code rate 2/3, guard band = ¼, data rate = 19.91 Mbps in 8 Mhz (vs 19.3 Mbps in 6 Mhz for VSB). Note that if the COFDM system were converted from an 8 MHz channel to 6MHz to be directly comparable to the VSB system, the useful data rate would be only 14.8 Mbps. **Table 2** shows some results.

Table 2

	COFDM 8 MHz	VSB 6 MHz
S/N required (f)	19.8 dB (a)	15.2 dB (c)
With 0 dB echo	25.2 to 27 .7 (b)	Not applicable
With –6 dB echo	21.5 to 21.7 dB (b)	17.5 to 18 dB (d)
With echo ensembles	20.3 to 23.2 dB (e)	16.4 to 18.5 dB (e)

Notes:
(a) ideal performance of 16.5 dB + implementation loss of 3.3 dB
(b) simulated ideal performance + implementation loss of 3.3 dB
(c) ATTC measured value standardized for planning purposes, includes implementation
(d) unpublished test results
(e) COFDM: Ricean (ghost energy –10 dB) and Rayleigh channel models. VSB: 5-echo ensembles, ghost energy –7.55 dB.
(f) Threshold for DVB is equivalent to one bit error per hour. Threshold for VSB is equivalent to one segment error per second. This difference corresponds to a S/N adjustment of less than 0.5 dB.

For SFN network operation (ghosts of maximum amplitude and delay), there is a large noise enhancement penalty in COFDM, to a level of impracticability in the worst cases. This situation can be eased most economically by use of an antenna with moderate directivity, which also makes use of VSB completely feasible. The VSB system has much less overhead than COFDM The robust synchronization features of the VSB system use very little of the raw data capacity, while allowing near-theoretical performance under fringe (white noise) conditions.

6. CONCLUSION

The VSB DTV transmission system has been shown to be robust in both laboratory and field testing. This ruggedness comes from the use of a low-level pilot and segment/framing syncs as well as VSB modulation. Also, each of these loops acts essentially independently from subsequent ones, allowing optimum and near-theoretical results. 4-VSB can be successfully transmitted with any existing MMDS equipment in the field today, and most systems built since 1991 are also capable of transmitting 8-VSB.

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ACKNOWLEDGMENTS

This paper could not have been completed without the help of Carl Eilers and Richard Citta of Zenith Electronics Corp., and the kind assistance of Christy Kehlbeck at ATSC.

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