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TRANSMISSION MEASUREMENT AND COMPLIANCE FOR DIGITAL TELEVISION

ATSC STANDARD

ADVANCED TELEVISION SYSTEMS COMMITTEE

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FOREWORD

This standard was prepared by the Advanced Television Systems Committee (ATSC) Technology Group on Distribution (T3). The document was approved by the members of T3 on July 23, 1997 for submission by letter ballot to the membership of the full ATSC as an ATSC Standard. The document was approved by the members of the ATSC on November 17, 1997.

1. SCOPE

This ATSC Standard document describes methods for testing, monitoring, and measurement of the transmission sub-system intended for use in the digital television (DTV) system.

Further, this document describes specifications for maximum out-of-band emissions, parameters affecting the quality of the inband signal, symbol error tolerance, phase noise and jitter, power, power measure, frequency offset and stability. In addition, the condition of the RF symbol stream upon loss of MPEG packets is described.

2. NORMATIVE REFERENCES

The following documents contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below.

[1] ATSC Standard A/53, ATSC Digital Television Standard.

[2] ATSC Standard A/52, Digital Audio Compression (AC-3).

[3] IEEE Standard, 100-1992, The New IEEE Standard Dictionary of Electrical and Electronic Terms.

[4] IEEE Draft Standard P1380, Standard Test Methods for Measuring the Spectrum Characteristics of Digitally Modulated Television Signals.

[5] IEEE Draft Standard P1381, Standard Test Methods for Measuring the Power of Digitally Modulated Television Signals.

[6] IEEE Draft Standard P1382, Standard Test Methods for Measuring the Transmission System Performance of Digitally Modulated Television Signals.

[7] ITU-R Document 11-3/TEMP/8-E, Further Development of Draft New Recommendation [TG 11/3-XXJ]: Spectrum Shaping Limits for Digital Terrestrial Television Broadcasting.

3. COMPLIANCE NOTATION

As used in this document, *"shall"* or *"will"* denotes a mandatory provision of the standards. *"Should"* denotes a provision that is recommended but not mandatory. *"May"* denotes a feature whose presence does not preclude compliance, that may or may not be present at the option of the implementers.

4. TRANSMISSION MEASUREMENT AND COMPLIANCE

4.1 8-VSB modulation (Trellis coded)

4.1.1 Maximum Out-of-Band Spectrum Emissions

4.1.1.1 Specification of DTV out-of-band radiation to protect adjacent channel NTSC assignments

The out-of-band measurement specification defined in this section is based upon measurements made at the Advanced Television Test Center (ATTC) to determine NTSC's Threshold of Visibility (TOV) for 500 KHz wide noise sources centered at various points across the NTSC channel. This work determined an appropriate "weighting function," which is rounded to the nearest dB to obtain this specification. A "weighting function" approach allows some flexibility in spectral sidelobe details, while still achieving completely adequate protection of adjacent channels. The mask is defined in terms of Desired-to-Undesired ratio (D/U) and a 500 KHz measurement bandwidth. This definition specifically recognizes that the required attenuation of DTV spectral sidelobes depends on the relative power levels of the DTV signal and an NTSC signal in the adjacent channel over the DTV coverage area.

Work done at ATTC showed that noise with a flat spectrum across the 6 MHz NTSC channel which has a power that is at least 51 dB below NTSC peak of sync was adequate to avoid TOV interference with the NTSC signal, based on the median of the receivers tested. Weighting such a flat spectrum of noise with the weighting function results in a weighted TOV power level which is 5 dB lower, or at 56 dB below NTSC peak of sync power.

For various shaped noise distributions across the NTSC channel, it has been verified that as long as the weighted noise is at least 56 dB below NTSC peak-of-sync power, then TOV is avoided. Here, the NTSC noise interference is viewed as arising from the spectral sidelobes of an adjacent channel DTV transmitter. If the ratio of DTV average power to NTSC peak-of-sync power is $\left(\frac{DTV}{NTSC}\right)_{dB}$, then to avoid NTSC TOV the DTV sidelobes in the adjacent NTSC channel, when weighted and summed across the channel, must be attenuated below average DTV transmitter power by at least $\left(56+\left(\frac{DTV}{NTSC}\right)_{dB}\right)$ dB. For example, if the DTV average power is 12 dB below the NTSC peak power, $\left(\frac{DTV}{NTSC}\right)_{dB}$ = -12 dB, so the weighted DTV sidelobe power in an adjacent channel needs to be attenuated at least 56 - 12 = 44 dB below average DTV signal power for this case.

Further work done at the ATTC determined that in order to avoid the Threshold of Audibility (TOA) on the NTSC audio channel, the power measured in the upper 500 kHz segment of the NTSC channel must be attenuated at least 48 dB below NTSC peak of sync power, or 48 + $\left(\frac{DTV}{NTSC}\right)_{dB}$ dB below the DTV average power. This was for a ratio of audio-to-video carrier powers of -13 dB. Less attenuation is required for higher audio-to-video ratios.

The protection of the adjacent NTSC channel against TOV and TOA leads to the following out-of-band DTV spectral emission regulation:

(a) To protect against adjacent channel NTSC TOV, out-of-band DTV spectral emissions measured in an adjacent 6 MHz wide channel, when weighted by the weighting function, shall be attenuated below the DTV average transmitter power by at least 56 + $\left(\frac{DTV}{NTSC}\right)_{dB}$ dB.

(b) Additionally, to protect against adjacent channel TOA, the power measured in the uppermost 500 kHz segment of an adjacent channel shall be attenuated below DTV average power by at least 48 + $\left(\frac{DTV}{NTSC}\right)_{dB}$ dB. This assumes an audio-to-video carrier power ratio of -13 dB.

(c) Finally, the unweighted power in any non-adjacent 6 MHz channel shall be attenuated below DTV average power by at least 60 dB.

WHERE:

$$\left(\frac{DTV}{NTSC}\right)dB = 10\log_{10}\left(\frac{Average\ \ Power\ \ of\ \ the\ DTV\ \ Signal}{PK.\ Sync\ \ Power\ \ of\ \ Adj.\ channel\ \ NTSC\ \ Signal}\right)_{MAX}$$

i.e., the maximum ratio of received DTV power compared to an adjacent NTSC channel power at any location within the DTV coverage area where the NTSC channel's coverage must be protected. This measured ratio includes any effects of different DTV and NTSC antenna patterns.

The algorithm to determine weighted noise power of a spectral density distribution across a 6 MHz NTSC Television channel is as follows:

The distribution is divided into twelve 500 KHz frequency bands. Beginning with the band at the low frequency end of the channel, the power in each band, in turn, is weighted (attenuated) with the following weighting function sequence: -27dB, -13dB, -3dB, -2dB, 0dB, -1dB, -4dB, -9dB, -10dB, -4dB, -10dB, minus infinity dB. The total weighted picture interference is the power sum of all 12 weighted bands. [See above: 4.1.1.1 (a).] The weighting function is plotted in Figure 4.1.

The sound interference is determined by the 12th frequency band only and is weighted by 0dB. [See above: 4.1.1.1 (b).]

4.1.1.1.1 Specification of DTV out-of-band Emission Mask from FCC 6th Report and Order, Released April 21, 1997

The order requires that transmitter out-of-band emissions be attenuated consistent with the following:

(1) at the channel edge, emissions must be attenuated no less than 46 dB below the average transmitted power;

(2) more than 6 MHz from the channel edge, emissions must be attenuated no less than 71 dB below the average transmitted power; and

(3) at any frequency between 0 and 6 MHz from the channel edge, emissions must be attenuated no less than the value determined by the following formula, which is based on a measurement bandwidth of 500 kHz.

Attenuation in dB = $46 + [(\Delta f)^2/1.44]$; where Δf = frequency difference in MHz from the edge of the channel.

4.1.1.2.1 Specification of DTV out-of-band radiation using a weighting function to quantify the interference to first adjacent channel NTSC assignments

When the interference level of the spectral distribution defined by the Emission Mask in 4.1.1.1.1 is not low enough, other spectral distributions should be considered.

4.1.1.2 Specification of DTV out-of-band radiation to protect adjacent channel DTV assignments

In the case where there are no NTSC adjacent channel assignments, it is recommended that the out-of-band radiation from co-located DTV transmitters that comply with the requirement of the emission mask specified in the FCC 6th Report and Order Released April 21, 1997 be controlled:

(1) For 0.1 dB degradation to the fringe area performance (15dB SNR) of a DTV channel having DTV adjacent channel assignments, the sum of authorized effective radiated powers of the adjacent channels should not exceed six (6) times the authorized effective radiated power of the transmitter of that DTV channel, and

(2) For 0.25 dB degradation to the fringe area performance (15 dB SNR) of a DTV channel having DTV adjacent channel assignments, the sum of authorized effective radiated powers of the adjacent channels should not exceed sixteen (16) times the authorized effective radiated power of the transmitter of that DTV channel.

If the center channel of three DTV assignments is taken as the reference desired channel (N), the spectral spillover from each adjacent channel (N+1, N-1) is power additive as interference to the desired (N) channel. Since the spectral spillover power bears a direct relationship to the authorized power of the channel transmitter causing it, the sum of spectral spillover coming from the channel on both sides, i.e. the interference to the desired channel (N), is directly proportional to the sum of the effective radiated powers in the adjacent channels (N+1, N-1).

Where the weighting transmitter side-lobe power (N+1 or N-1) is lower than minus (-) 40 dB, interference level to the desired channel (N), (due to transmitter filtering, and/or improved linearity), the permitted effective radiated power of such a DTV transmitter is increased in direct proportion to that side-lobe power reduction.

4.1.2 In-band signal characterization

The quality of the in-band emitted signal can be specified and measured by determining the departure from 100% "eye" opening. The departure, or error, has three components: 1) circuit or "white" noise, 2) intermodulation noise caused by non-linearities, and 3) intersymbol interference. The combination of all of these effects can be specified and measured by an error vector magnitude.

The error vector magnitude for a DTV signal shall be no greater than -27 dB relative to the authorized power. An error vector of this maximum level will reduce the received DTV threshold by 0.25 dB, which corresponds to a reduction of approximately 1/4 mile in coverage distance from the transmitter.

4.1.3 Symbol rate tolerance

The symbol rate shall be

$$f_{sym} = 4.5 \cdot \frac{684}{286}\ MHz \quad \pm 30\,Hz \approx 10,762,237.8\ Hz$$

Notes:

(1) The symbol rate f_{sym} is locked to the transport stream date rate f_{tp} in the exact ratio:

$$f_{sym} = \frac{1}{2} \cdot \frac{208}{188} \cdot \frac{313}{312} \cdot f_{tp}$$

The approximate value of f_{tp} is: ~19,392,658.5 ± 54 Hz.

(2) The tolerances on f_{sym} and f_{tp} provide a reference suitable for generation of the NTSC color subcarrier frequency in devices which translate the digital signal to NTSC, to a tolerance of ± 10 Hz.

4.1.4 Phase noise and jitter

The level of phase noise shall be no greater than -104 dBc/Hz @ 20 KHz

4.1.5 Power specification and measurement principles

Background: The present NTSC service allows a power variation ranging between 80% and 110% of authorized power. These values correspond to -0.97 dB and +0.41 dB respectively. Because of the so-called "cliff effect" at the fringes of the service coverage area for a digital DTV signal, the allowable lower power value will have a direct effect on the DTV threshold. A reduction of 0.97 dB in transmitted power will change the DTV threshold of 14.9 dB (which has been determined to cause a 3×10^{-6} error rate) to

15.87 dB, or approximately a one mile reduction in coverage distance from the transmitter.

Therefore, the average power of the DTV transmitted signal shall be specified and measured as follows:

The lower allowed power value be 95% of authorized power and the upper allowed power value be 105% of authorized power.

A conventional full-wave rectifier type of power meter will register approximately 1 dB lower than the true power on "white" noise. It has not been determined what the reading will be when measuring DTV power, but it is likely to be different than with "white" noise. It is suggested that DTV stations use a calorimeter type true power measurement method to re-calibrate the rectifier type of power meter if used. The power reading should have an uncertainty no worse than 5%, and preferably better, in order to have minimum impact on DTV coverage.

4.1.6 Frequency offsets and stability

Several interference mechanisms must be considered in selecting the DTV frequency assignments. These are (1) DTV-to-DTV co-channel, (2) NTSC-to-DTV co-channel, and (3) DTV-to-NTSC upper adjacent channel. Other interference effects (i.e., lower adjacent, taboos, DTV-to-NTSC co-channel, etc.) are insensitive to frequency offset. In each case, the dominant interference will determine which frequency offset will have precedence. The DTV offsets in each case below track the assigned offsets to the NTSC station (i.e., -10 kHz, 0 kHz, + 10 kHz).

These proposed offsets are not modifications to the ATSC Standard. Rather, these offsets are specific solutions that account for interference effects encountered during the actual channel allocation process.

CO-CHANNEL DTV-TO-DTV OFFSET

In the DTV co-channel interference condition, it has been found that a DTV frequency offset that is an odd multiple of half the DTV segment rate provides improved interference rejection. There are several choices that meet this requirement. An offset of 1.5 times the segment frequency (i.e., 19,403 Hz) appears to provide the best performance. The frequency tolerance of the DTV transmitters is ± 10 Hz.

CO-CHANNEL NTSC-TO-DTV OFFSET

For the NTSC-to-DTV co-channel interference condition, the best performance is obtained if the DTV signal is aligned such that the NTSC visual carrier is located near the notch of the receiver comb filter. Additionally, the DTV receiver clock recovery performance is most robust if the visual carrier location is chosen to be near an odd multiple of half of the segment frequency. It has been shown that the choice that places the DTV pilot below the NTSC visual carrier by 70.5 times the segment frequency (i.e., 911,944 Hz) provides the best performance. This has a tolerance of ±1 kHz.

UPPER ADJACENT CHANNEL DTV-INTO-NTSC OFFSET

For interference caused by the upper adjacent DTV-into-NTSC, tests at the ATTC have shown that the DTV pilot carrier may appear as a chrominance beat in the NTSC image on some sets. An improved alignment between the DTV pilot and the NTSC chroma subcarrier is selected to be an odd multiple of half the NTSC line rate. This causes the chrominance beat pattern to alternate at the NTSC line rate. This reduces the visibility of the chroma beat interference by several dB. The offset proposed by the ATTC is 95.5 times the NTSC horizontal rate. This allows a tolerance of ±1 kHz on both the NTSC and DTV transmitters. The frequency of the DTV pilot can be expressed in terms of the frequency of the NTSC visual carrier on the lower channel and the NTSC horizontal rate.

$$F_p(n) = F_v(n-1) + \frac{455}{2} F_h + 95.5F_h$$

The ATTC found that when this frequency is chosen as the offset, an underlying high-frequency luminance beat of 5.0821678 MHz is also then produced. This interference was most visible during the ATTC test since only a pilot carrier, and not the full DTV signal was tested. The ATTC has proposed an additional refinement to the offset between the DTV and NTSC signals to produce an alternating beat pattern at both the NTSC frame and line rates. This proposal specifies a difference between the DTV pilot and the NTSC chroma carrier of 95.5 times the NTSC line rate minus the NTSC frame rate.

$$F_p(n) = F_v(n-1) + \frac{455}{2} F_h + 95.5F_h - 29.97$$

This additional refinement provides a reduction in visibility of upper adjacent DTV interference into NTSC, but it requires a tighter frequency control on the NTSC transmitter to maintain within a frequency difference ±3 Hz.

4.1.7 Synchronization signals

It can be expected that in broadcast operations sometimes the transmission modulator will be fed with corrupted MPEG packets, which can result in loss of, or incorrectly timed, sync and clock signals. In such cases, the receiver will go out of lock and thereby prolong the disruption of service.

The transmitted RF VSB symbol stream should retain continuity throughout the time of loss of MPEG-packets at the VSB modulator input. VSB segment and field syncs should be transmitted at all times, with no significant phase discontinuities, and the symbol clock frequency should remain within the ± 2.7 ppm tolerance without significant phase discontinuity. Once MPEG-data is determined to be absent or corrupted, a null MPEG-packet should be inserted into the path prior to the VSB processing (i.e. randomizing, Reed Solomon encoding, interleaving, trellis encoding, etc.).

4.2 *16-VSB modulation*

4.2.1 Emission mask

The present rules in Federal Communication Commission Regulation Part 76.605, Technical Standards, cover specifications for disturbances such as intermodulation, which are entirely adequate for 16-VSB signal carriage by high data rate media, and therefore no specific emission mask is required.

4.2.2 In-band signal characterization

The quality of the in-band signal as received can be specified and measured by determining the departure from 100% "eye" opening. The departure, or error, has three components: 1) "white" noise, 2) intermodulation disturbances caused by non-linearities, and 3) intersymbol interference. The combination of all of these effects can be specified and measured by an error vector magnitude. The first component will be no worse than -43 dB relative to peak of NTSC sync as measured in a 4 MHz band. The equivalent in 6 MHz is -41.2db. The 16-VSB signal level is 6db lower than the equivalent NTSC sync. Therefore, the maximum noise level relative to the 16-VSB signal average power in a 6 MHz band is -35.2dB. The second component intermodulation disturbances are required to be -47dB relative to NTSC peak of sync or, equivalently, -41dB relative to 16-VSB average power. The third component, intersymbol interference, is best measured and specified at the output of the 16-VSB modulator. The power sum of the three components is the error vector.

The theoretical signal to noise ratio threshold for 16-VSB modulation which produces a bit error rate of 3×10^{-6} is 28.4dB. Therefore, and intersymbol interference error vector magnitude for 16-VSB signal no greater than -32dB relative to the 16-VSB power will produce a total error vector magnitude no greater than -31.4dB which is a margin with respect to the threshold of 28.4dB of 3dB.

4.2.3 Symbol rate tolerance

The symbol rate shall be

$$f_{sym} = 4.5 \cdot \frac{684}{286}\ MHz \ \ \pm 30\,Hz \approx 10{,}762{,}237.8\ Hz$$

Notes:

1) The symbol rate f_{sym} is locked to the transport stream date rate f_{tp} in the exact ratio:
   $$f_{sym} = \frac{1}{4} \cdot \frac{208}{188} \cdot \frac{313}{312} \cdot f_{tp}$$
   The approximate value of f_{tp} is: ~38,785,316.9 ±108 Hz.

2) The tolerances on f_{sym} and f_{tp} provide a reference suitable for generation of the NTSC color subcarrier frequency in devices which translate the digital signal to NTSC, to a tolerance of ± 10 Hz.

4.2.4 Phase noise and jitter

The level of phase noise shall be no greater than -104dBc/Hz @ 20khz.

4.2.5 Signal Level Specification

The service provider shall provide, at the receiver, -6dBmV average signal level in 6 MHz. Since the noise and other disturbances are specified with respect to the signal level, there is no effect on 16-VSB threshold and therefore no other signal level specification is required.

4.2.6 Frequency stability

The frequency tolerance should not exceed +/- 1kHz.

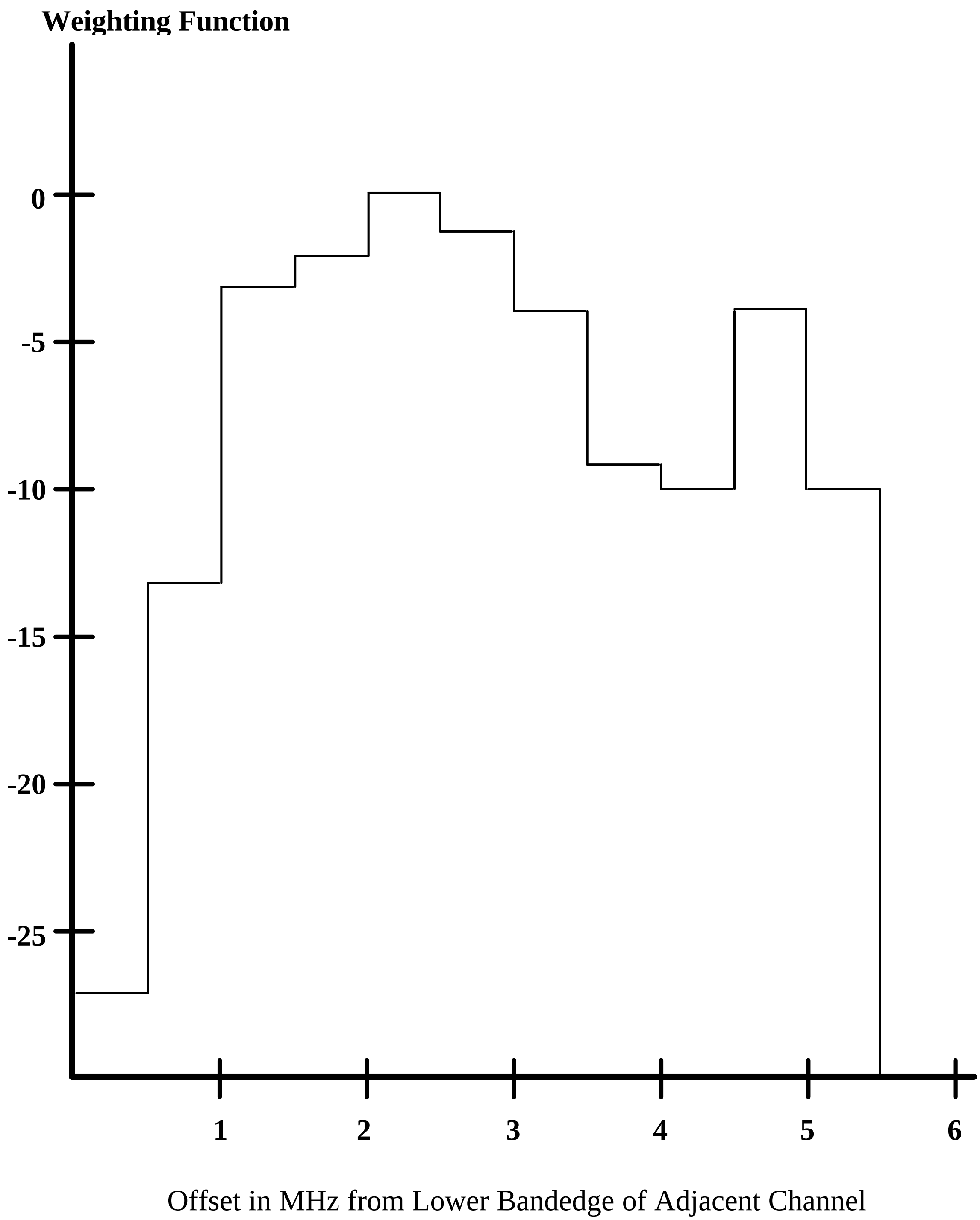

Figure 4.1 Picture Interference Weighting Function