IEEE P1631™/D3
Draft Recommended Practice for Measurement of 8-VSB Digital Television Mask Transmission Compliance for the USA

Sponsored by the

RF Standards Committee G-2.2

of the

IEEE Broadcast Technology Society

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Introduction

This introduction is not part of IEEE P1631/D2, Recommended Practice for Measurement of 8-VSB Mask Compliance in the USA

Overview

This (draft) Recommended Practice presents the theory, requirements, and techniques required to obtain accurate and consistent measurements of 8-VSB DTV Emissions in the transmitter's adjacent Channels. It is intended to provide manufacturers, installers, TV station personnel and other concerned parties with a standardized body of information for the purpose of determining whether DTV transmission systems are in compliance with the specifications prescribed in the FCC rules. While the practices within this document apply specifically to the FCC's rules in the United States, the background theory and the measurement techniques apply to 8-VSB DTV Emissions world wide.

History

A digital television (DTV) standard was developed for the United States by the Advanced Television Standards Committee (ATSC). In the late 1990's, the FCC adopted the ATSC's transmission standards by incorporation (i.e., the ATSC's standards are referred to in the FCC's rules) but adopted its own regulations for DTV transmitter out-of-Channel Emissions performance.

Subsequently, in 2002, discussions between the IEEE Broadcast Technology Society (BTS) and ATSC resulted in the BTS agreeing to provide assistance to develop the methodology required to measure DTV signals. A major driver of the BTS's participation was instances where significantly different results were obtained when measuring the same transmitter. At that time, it was unclear whether the primary problem was variations in the measurement techniques or in the test equipment. The impact was that there was little certainty whether or not a given transmitter was in complete compliance with the FCC's rules or not. Thus, it was important for the BTS to define instrument performance and to codify measurement protocols so that comparable results could be obtained by all parties. A Project Authorization Request (PAR) was sponsored by the IEEE BTS to start the project and the RF Standards Committee G-2.2 was identified as the working group to investigate and develop the necessary information.

The in-Channel spectrum of the 8-VSB DTV signal is similar to other digitally modulated RF signals. However, the FCC's out-of-Channel emission requirements are very severe and are couched in language specific to DTV. This, coupled with the fact that the techniques required to measure the spectrum of a digitally-modulated transmitter are unfamiliar to the broadcast industry, caused significant variations in the results obtained by various observers. Therefore, it was determined by the BTS RF Standards Committee that its initial project would be to develop an 8-VSB Emissions measurement Recommended Practice. The project turned out to be much more difficult than thought, and has evolved over the past 5 years with significant effort by a dedicated a group of individuals. Two factors made developing the document difficult. The first is that FCC's requirements are very rigorous, pushing the performance of available test equipment its limits. The second, to obtain that performance, required that the test equipment be carefully configured so the document had to provide sufficient, suitably worded instruction for those unfamiliar with the equipment's operation.

The committee collected the necessary background theory and then evaluated the methods and the suitability of the test equipment available for making the measurements. After several field trials and an informal poll of industry members concerning the acceptability of various techniques, a direct measurement technique requiring the use of a band stop filter in the RF sample path was selected as the primary method. Field tests of the consistency of measurements made by different models of test equipment as well as of the clarity and understandability of the document's language were made. A verification report was created that documents the measurements made at 2 transmitters with multiple instruments. This report documents that the goals outlined by this Recommended Practice were essentially achieved. This report is available from the BTS G-2.2 RF Standards Committee.

The measurement of harmonic Emissions was initially included in this document. However, significant obstacles prevented reaching closure on an acceptable and practical means of measuring the harmonics of both existing and future transmitters. These obstacles included issues caused by moding of harmonic energy in the transmission line (or wave guide) and associated RF directional coupler characteristics. It was therefore decided to proceed with the adjacent Channel portion of the Emissions document for the industry's use while the harmonic problem is further considered. It is hoped that as the harmonic Emissions measurement problem is resolved, a future amendment can be incorporated into this document.

Patents

Attention is called to the possibility that implementation of this document may require use of subject matter covered by patent rights. By publication of this document, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents or patent applications for which a license may be required to implement an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

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Contents

Draft Recommended Practice for Measurement of 8-VSB Mask Compliance for the USA

1 Scope

This document provides a standardized body of theory, techniques and procedures for measuring the spectral characteristics of 8-VSB transmitters used for terrestrial transmission of digital television (DTV) in the frequency range near their assigned Channels. Essential characteristics are specified and measurement procedures are given that ensure that all parties will obtain comparable results. The theory and techniques presented are applicable to *all* 8-VSB transmitters. However, the specification and interpretation of these measurements is primarily focused on DTV transmitters used within the United States of America.

2 Normative References

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

FCC regulations for DTV within 47CFR§73 Subpart E-Television Broadcast Stations

- FCC 47CFR§73.606(a)
- FCC 47CFR§73.622(g)
- FCC 47CFR§73.682(a)1
- FCC 47CFR§73.682(d)

FCC regulations for LPTV DTV Broadcast Stations within 47CFR§74 Subpart G-Low Power TV, TV Translator, and TV Booster Stations

- FCC 47CFR§74.794(a)
- FCC 47CFR§74.794(b)

FCC Public Notice DA-05-1321A1, May 10, 2005, “OET Clarifies Emission Mask Measurement for DTV Transmitters”

All FCC regulations and public notices are available from the FCC’s web site www.fcc.gov. The ATSC standard is available from the ATSC website www.atsc.org.

3 Definitions

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B1][1] should be referenced for terms not defined in this clause. For convenience, useful terms defined in that document are given in the Glossary in Annex C.

3.1 Band Power Measurement (also called Channel Power): A measurement system included in most measurement instruments that automatically measures the total average power of the signal(s) present within a frequency range selected by the user.

3.2 Channel: The nominal specified range of frequencies assigned to each 6 MHz television Channel in North America.

(See 4.2).

3.3 Channel Edge: The upper or lower edge of the 6 MHz wide Channel occupied by the 8-VSB signal from a DTV transmitter.

3.4 Channel Filter: A band pass filter typically used at the output of a DTV transmitter to limit its out-of-Channel Emissions. Sometimes known as an Emissions Mask Filter.

(See Figure 21 or Figure 22).

3.5 $\mathbf{dB_{DTV}}$: An amplitude measure of spectral details of an 8-VSB signal where the amplitude of the noise-like signal is either *measured* across a 500 kHz range of frequencies or *normalized* to a 500 kHz bandwidth, and then expressed as a logarithmic ratio to the total average power of the 8-VSB signal within its 6 MHz Channel. *(See 4.4)*

3.6 Emissions: All electromagnetic signals emanating from the transmitter via its antenna transmission line. Emissions include the *desired* fundamental signal itself plus all *undesired* electromagnetic signals at frequencies not within the transmitter's assigned Channel including, but not limited to, adjacent Channel (or channel) signals, harmonic signals, sub-harmonic signals and spurious responses.

3.7 Emissions Mask Filter: A band pass filter typically used at the output of a DTV transmitter to limit its out-of-Channel Emissions. Sometimes known as a Channel Filter.

(See: *Figure 21 or Figure 22*)

3.8 Frequency Response: The variation of a transmitter's actual amplitude response at a given frequency with respect to its ideal response; typically expressed in dB. In the 8-VSB DTV transmitter, the ideal response is a flat mid-band amplitude response with two root-raised cosine transition regions at the Channel Edges. [B2]

3.9 $\mathbf{F_{Symbol}}$: The approximately 10.762 238 MHz rate that data *symbols* are transmitted in the 8-VSB system. [B3]

(See 4.3)

3.10 Head or Signal Head: The flat, central portion of the 8-VSB signal

3.11 Head-Shoulder Intercept (HSI) or 8-VSB HSI: A measure of a device's intermodulation performance when handling an 8-VSB signal. 8-VSB HSI is the total average signal amplitude that would (by extrapolation) cause the signal's Channel edge Shoulder to be equal in amplitude to the signal's Head. (*See Annex A*)

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[1] The number in brackets correspond to those of the bibliography in Annex C

3.12 Near-Channel: A loosely defined range of frequencies near the 8-VSB DTV transmitter's assigned Channel (e.g., within approximately a dozen MHz of the Channel's center frequency).

3.13 Noise Bandwidth: An attribute of either a filter or a signal. It is the bandwidth of an idealized (i.e., rectangular shaped) response that has the same peak amplitude response and passes the same noise power as the actual filter or signal; also referred to as Equivalent Noise Bandwidth.

(See 6.1.1)

3.14 Pilot Frequency: The frequency of the 8-VSB signal's pilot carrier.

(See 4.2 and Figure 2)

3.15 Out-of-Channel Emissions: Any emission that the 8-VSB DTV transmitter produces outside of its Channel.

(See 4.6).

3.16 Sampling Device: A directional coupler or attenuator used to obtain a portion of the transmitted signal for use by the measurement instrument. The Sampling Device is typically placed in the transmission line (e.g., the coaxial cable or the waveguide) connecting the transmitter to its load (normally the antenna). When a directional coupler is used, it selectively provides a sample of the signal traveling from the transmitter toward its load while rejecting the signal reflected from the load.

(See4.5 and 5.4.2).

3.17 Shoulder: The "shelf" of third-order intermodulation products in the frequency range immediately beyond the transmitter's assigned Channel. Since it is primarily caused by third-order intermodulation, its amplitude increases three times faster than the total 8-VSB signal's power. Its amplitude is generally measured with respect to the amplitude of the Head or flat portion of the 8 VSB spectrum. This is the most critical area in a transmitter's out-of-band Emissions because the transmitter's Channel Filter is often ineffective near the edge of the transmitter's Channel.

(See 6.2.2 and Figure 1)

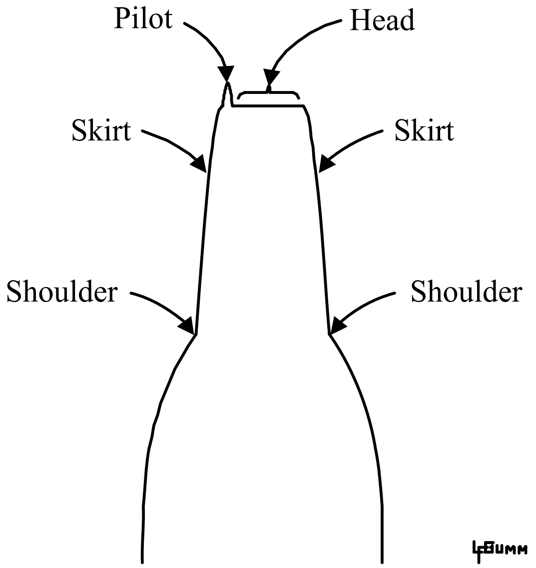

Figure 1−Parts of the 8-VSB signal

3.18 Slope Attenuation Factor: When dealing with a Channel Filter's attenuation vs. frequency characteristic expressed in dB, portions of the curve between two frequencies may be modeled as a linear slope. The Slope Attenuation Factor is the difference, in dB, between the midpoint attenuation of that slope and the *average* attenuation computed over the entire slope.

(See 6.3.2.4)

3.19 Sub-Band: One of twenty-four 500 kHz wide frequency bands in the 6 MHz Channel directly above and directly below the 8-VSB DTV transmitter's Channel. They are numbered in a sequence of ±1 to ±12, with 1 being directly adjacent and 12 being the farthest from the Channel Edge. Positive numbers are assigned to the Sub-Bands *above* the transmitter's Channel and negative numbers to those *below*.

(SeeFigure 6)

3.20 Sweet Spot or Sweet Spot Amplitude: The 8-VSB signal amplitude at the measurement instrument's input mixer that maximizes the measurement instrument's dynamic range.

(See 6.2.4, 6.2.5 and 6.2.6)

3.21 Third Order Intercept (TOI or IP3): When two signals of equal amplitude and nearly the same frequency are applied to an active device's input, spurious intermodulation products caused by the device's third order non-linearities may be generated. If the two signals are separated by ΔF, one spurious of interest product will appear at a frequency ΔF above the frequency of the higher signal and another at ΔF below the frequency of the lower signal. Over a considerable range of input amplitudes, the amplitude of each spurious product increases 3 dB for each 1 dB increase in *both* of the two input signals' amplitude. The device's Third Order Intercept (i.e. its TOI or its IP3) is, by extrapolation, the signal amplitude at which the individual spurious products are equal in amplitude to the individual input signals. This value is never found by direct measurement because the 3:1 relationship between spurious product amplitude and the signal's amplitude (known as being "well behaved") fails well before the intercept amplitude is reached.

(See 6.2.2 and Figure 13).

4 8-VSB Signal Characteristics

4.1 General

In the USA, DTV transmission is specified by the FCC. The critical Emissions standards, the subject of this Recommended Practice, are wholly specified by the FCC itself while the detailed specification of the 8-VSB signal itself is specified by the FCC by reference to the ATSC's standard [FCC 47CFR§73.682(d)]. For the reader's convenience, the applicable portions of both the FCC's regulations and the ATSC's standards are repeated here. While correct at the time of writing, this information may have been superseded and should not be considered authoritative. The reader is urged to reference the source documents, especially the FCC's DTV Emissions rules, to ensure that the correct FCC rules are applied to the measured values.

4.2 Pilot Frequency

The 8-VSB pilot is normally 309.441 kHz above the lower edge of the Channel assigned to the DTV transmitter, except when the DTV transmitter is required by the FCC to offset its Pilot Frequency in order to minimize interference caused to a lower adjacent Channel analog TV station. In that case, the Pilot Frequency is required to be 5.082,138 MHz (± 3 Hz) above the visual carrier of the analog station [FCC 47CFR§73.622(g)] [2],.

The exact Pilot Frequency of an offset 8-VSB transmitter is thus dependent upon the frequency of the analog transmitter. Because the nominal frequencies of some analog stations are offset 10 kHz lower in frequency, while others are offset 10 kHz higher [FCC 47CFR§73.606(a))] [3], the Pilot Frequency of an upper adjacent Channel 8-VSB transmitter will be about 12.697 kHz, 22.697 kHz or 32.697 kHz *higher* than nominal. Offset operation makes it more difficult for a DTV transmitter to meet the Emissions mask. A quantitative analysis of this problem is given in Annex B.

4.3 Frequency Response

The ideal frequency response of an 8-VSB transmitter is shown in Figure 2 [B2] [FCC 47CFR§73.682(a)1] [4].

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[2] Specifies exceptions to the standard Pilot Frequency.

[3] Specifies the use of 10 kHz offsets for some analog TV Channels.

[4] Specifies a 6 MHz Channel for television use.

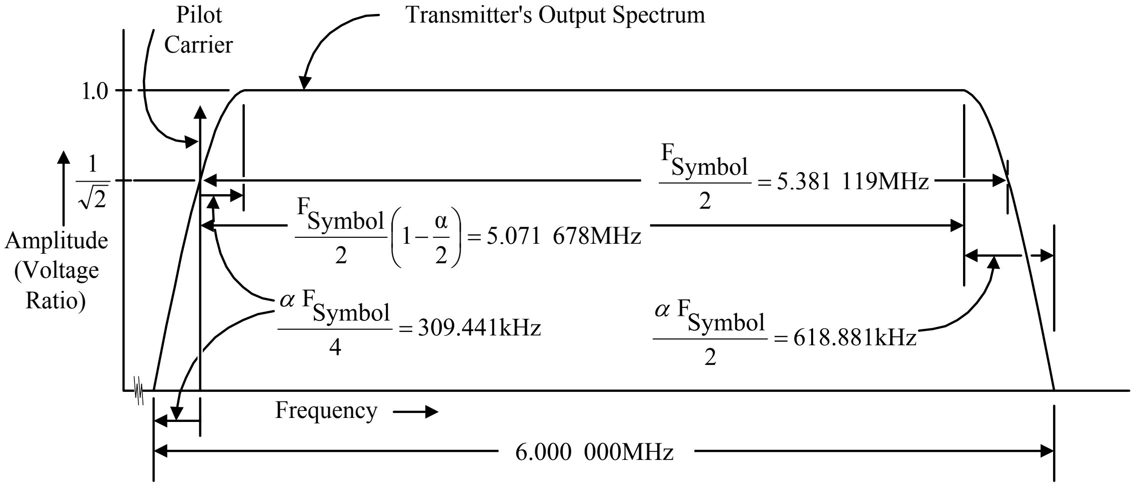

Figure 2−Ideal transmitter output spectrum

This curve may be expressed in equations as:

$$H(F) = \begin{cases} 0 & 0 < \mathrm{F} \le \left(\mathrm{F}_{\mathrm{Pilot}} - \frac{\mathrm{F}_{\mathrm{Symbol}}\alpha}{4}\right) \\ \sin\left[\frac{\pi\left(F - F_{Pilot} + \frac{F_{Symbol}\alpha}{4}\right)}{F_{Symbol}\alpha}\right] & \left(F_{Pilot} - \frac{F_{Symbol}\alpha}{4}\right) < F \le \left(F_{Pilot} + \frac{F_{Symbol}\alpha}{4}\right) \\ 1 & \left(F_{Pilot} + \frac{F_{Symbol}\alpha}{4}\right) < F \le \left(F_{Pilot} + \frac{F_{Symbol}}{2}\left(1-\frac{\alpha}{2}\right)\right) \\ \sin\left[\frac{\pi\left(\frac{F_{Symbol}}{4}(2+\alpha) - F + F_{Pilot}\right)}{F_{Symbol}\alpha}\right] & \left(F_{Pilot} + \frac{F_{Symbol}}{2}\left(1-\frac{\alpha}{2}\right)\right) < F \le \left(F_{Pilot} + \frac{F_{Symbol}}{2}\left(1+\frac{\alpha}{2}\right)\right) \\ 0 & \left(F_{Pilot} + \frac{F_{Symbol}}{2}\left(1+\frac{\alpha}{2}\right)\right) < F < \infty \end{cases} \tag{1}$$

where:

$\mathrm{F}_{\mathrm{Symbol}} = 4.5(684/286)10^6$ or $5(1539/715)10^6 \approx 10.762\ 238$ MHz (± 30 Hz) [B3] (2)

$\alpha = [2(6.000\ 000\ \mathrm{MHz})/\mathrm{F}_{\mathrm{Symbol}}] - 1 \approx 0.1150097$ (3)

4.4 Units for 8-VSB Emissions Amplitude Measurements

The FCC specifies the attenuation of Emissions in terms of measurements made with a 500 kHz reference bandwidth, expressed in dB with respect to the *total* power transmitted in the transmitter's 6 MHz Channel (including the pilot's power). Because of this quantity's complexity and its use in all measurements and regulations, it is given a special designation, $\mathrm{dB}_{\mathrm{DTV}}$ in this document.

Note: The amplitude of a measurement at a single frequency may also be expressed in dB_{DTV}. With the exception of the pilot signal, the 8-VSB signal is noise-like. Therefore, measured amplitudes vary directly with the measurement bandwidth. To express an amplitude measurement in dB_{DTV}, first scale that amplitude to a 500 kHz noise bandwidth using the procedure given in 6.1.1. Then divide that result by the transmitter's total average power measured within its Channel and express the result in dB. For amplitudes measured in dBm, measure the amplitude across a 500 kHz band or adjust the amplitude to a 500 kHz equivalent bandwidth using the procedure in 6.1.1 and then subtract the total average 8-VSB signal power (in dBm) to obtain the amplitude in dB_{DTV}.

4.5 Source of Signal to Be Measured

The FCC specifies that Emissions are to be measured on a signal derived from the transmitter's output at a point beyond any filters that may be employed [FCC 47CFR§73.622(h)]. Typically, a coupler or Sampling Device to obtain this signal is inserted in the transmission line (coaxial cable or waveguide) between the transmitter (including the mask filter) and its load or antenna. During measurement, the transmitter may be operated into either an antenna or a dummy load; the dummy load being preferred, as it minimizes possible problems with off-air signal ingress. As an option, the Sampling Device can be a simple attenuator of the correct impedance and one that can accommodate the transmitter's output power. Regardless of type, to make measurements possible, the Sampling Device should provide the measurement instrument with a signal of the appropriate amplitude. *(See 6.3.2.1)*

To enable accurate measurements of adjacent near-Channel Emissions, the Sampling Device should exhibit no more than 0.5 dB peak-to-peak flatness error over a minimum range of 18 MHz centered at the transmitter's output Channel. The Sampling Device should exhibit at least 18 dB of return loss over the 18 MHz range centered at the transmitter's output Channel. *(See 5.4.1)* The cables and connectors used to make connections between the Sampling Device and the test instrument should avoid the generation of passive intermodulation (PIM) distortion.

Note: Any frequency selectivity provided by any element in the transmission path leading to the antenna *after* the signal is delivered to the Sampling Device at the output of the transmitter's Channel Filter, is excluded from consideration by the FCC's regulations. [FCC 47CFR§73.622(h)]

4.6 Out-of-Channel Emissions

4.6.1 General

In the US, the FCC has specified different emission masks for different types of 8-VSB DTV transmitters.

One mask is specified for Full Service digital TV transmitters. Two other masks are specified for digital LPTV transmitters, Class A digital transmitters and digital TV translators; one mask is termed "Simple" and the other "Stringent". The conditions imposed by the licensing process and the FCC's regulations should be consulted to determine which mask is appropriate for a given digital transmitter.

4.6.2 Full Service DTV Transmitter Emissions Mask

Full Service transmitters should meet the following Out-of-Channel Emissions requirements [FCC 47CFR§73.622(h)]:

a) In the range between ½ the width of the Resolution Bandwidth filter used and 500 kHz from the Channel Edge:

$$Emissions \le -47\ \mathrm{dB}_{DTV} \qquad (4)$$

b) More than 6 MHz from the Channel Edge:

$$Emissions \le -110\ \mathrm{dB}_{DTV} \qquad (5)$$

c) At any frequency between 500 kHz and 6 MHz from the Channel Edge:

$$Emissions \le -(11.5(|\Delta F|-0.5)+47)\ \mathrm{dB}_{DTV} \qquad (6)$$

where:

ΔF is the frequency difference, in MHz, from the Channel Edge

These requirements are shown graphically in Figure 3.

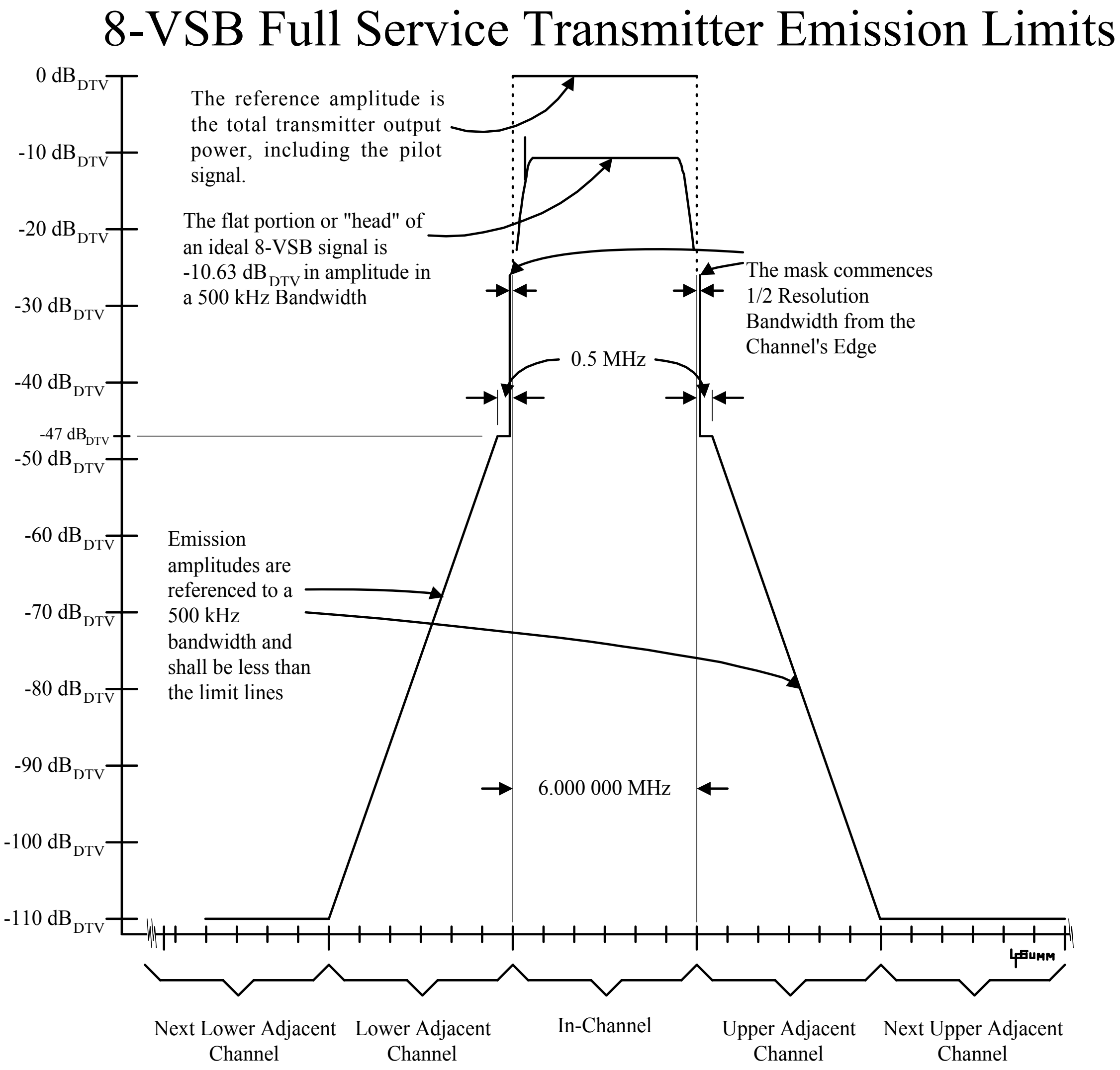

Figure 3−Emissions requirements for Full Service 8-VSB transmitters.

4.6.3 Stringent Emissions Mask for LPTV DTV Transmitters

Certain 8-VSB TV transmitters licensed for LPTV or translator service should meet the following out-of-Channel Emissions requirements [FCC 47CFR§74.794(a)]:

a) In the range between ½ the width of the Resolution Bandwidth filter used and 500 kHz from the Channel Edge:

$$\mathit{Emissions} \leq -47 \text{ dB}_{DTV} \tag{7}$$

b) More than 3 MHz from the Channel Edge:

$$\mathit{Emissions} \leq -76 \text{ dB}_{DTV} \tag{8}$$

c) At any frequency between 500 kHz and 3 MHz from the Channel Edge:

$$\mathit{Emissions} \leq -(11.5(|\Delta F|-0.5)+47) \text{ dB}_{DTV} \tag{9}$$

where:

ΔF is the frequency difference, in MHz, from the Channel Edge

Note: The FCC requires that the attenuation between the power amplifier's output terminals and the transmitter's output shall be verified for low power transmitters operating on certain Channels. (*See 4.7*)

These requirements are shown graphically in Figure 4.

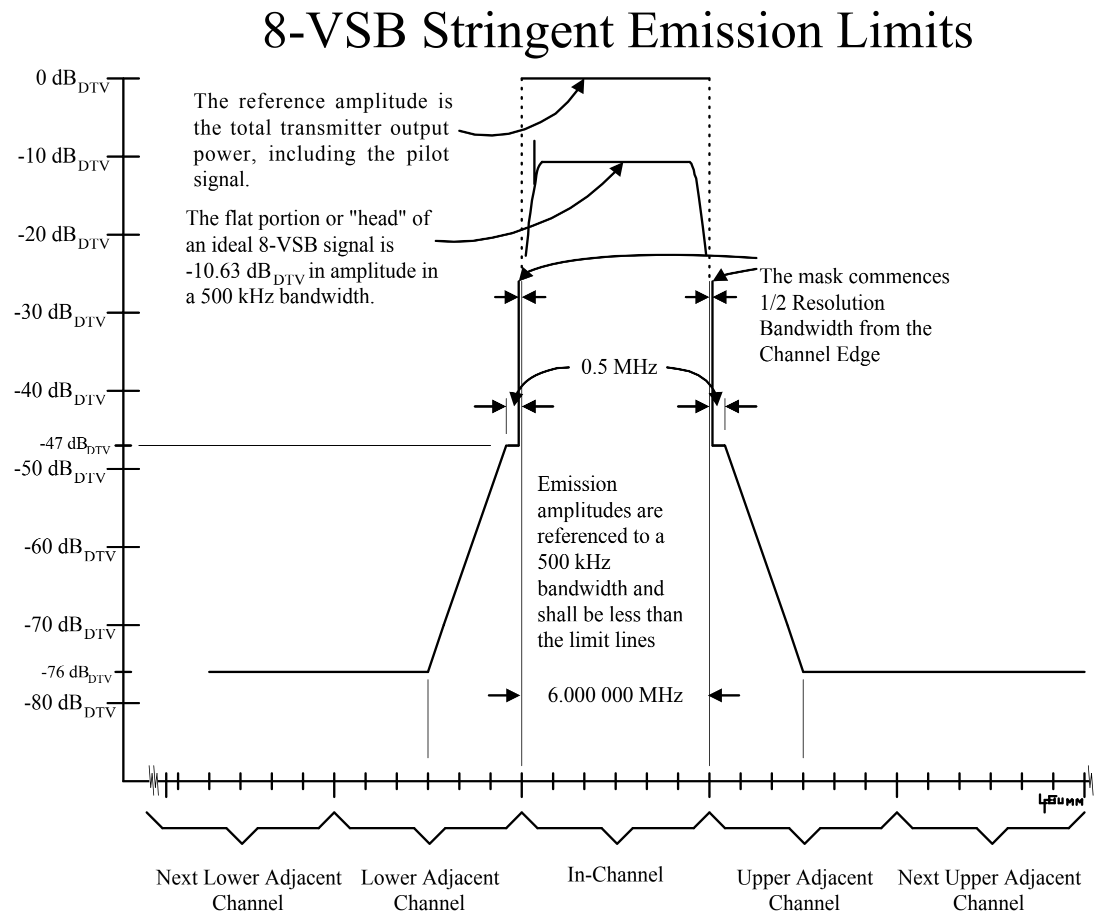

Figure 4−Stringent Emissions Mask requirements for 8-VSB LPTV transmitters and translators.

4.6.4 Simple Emissions Mask for LPTV DTV Transmitters

Certain 8-VSB TV transmitters licensed for LPTV or translator service should meet the following out of Channel Emissions requirements [FCC 47CFR§74.794(a)]:

a) In the range between ½ the width of the Resolution Bandwidth filter used and 6 MHz from the Channel Edge:

$$\mathit{Emissions} \le -((\Delta F^2/1.44) + 46)\ \mathrm{dB_{DTV}} \tag{10}$$

where:

ΔF is the frequency difference, in MHz, from the Channel Edge

More than 6 MHz beyond the Channel Edge:

$$\mathit{Emissions} \le -71\ \mathrm{dB_{DTV}} \tag{11}$$

These requirements are shown graphically in Figure 5.

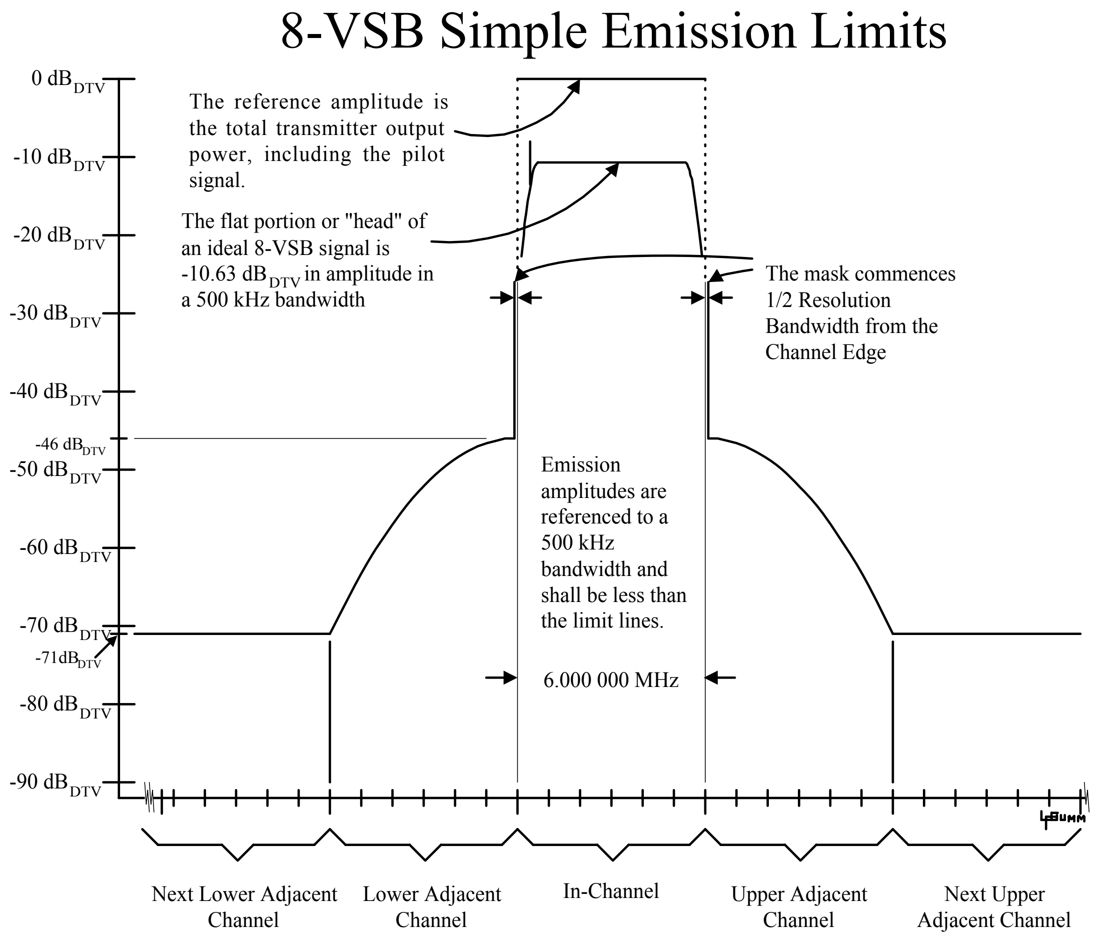

Figure 5−Simple Emissions Mask requirements for low power 8-VSB LPTV transmitters and translators.

Note: The FCC requires that attenuation between the power amplifier's output terminals and the transmitter's output shall be verified for low power transmitters operating on certain Channels. (*See 4.7*)

4.6.5 Notes for All Masks

Note 1: Measurements need not be made any closer to the Channel Edge than one half of the width of the Resolution Bandwidth filter used in the measurement instrument.

Note 2: While Figure 3, Figure 4, and Figure 5 depict only the band of frequencies near the transmitter's output signal, the FCC's ultimate attenuation requirement specifically applies to all Emissions greater than 6.0 MHz away from the transmitter's Channel Edges, including harmonics, sub-harmonics or other spurious signals.

Note 3: The FCC accepts measurements made using one of two methods [FCC Public Notice DA-05-1321A1, May 10, 2005, "OET Clarifies Emission Mask Measurement for DTV Transmitters"]:

Method 1: Measure the Emissions in a narrow Resolution Bandwidth (30 kHz, 10 kHz or narrower). Either scale the measured *power* to a 500 kHz bandwidth based on

10 log(500 kHz/noise bandwidth of the resolution filter) or scale the measured *attenuation* (i.e., 10log(measured power/total signal power)) based on 10 log(noise bandwidth of the resolution filter/500 kHz). These values are then compared *point by point* to the emission mask.

Method 2: Sum the power across a 500 kHz window in order to implement an effective measurement bandwidth of 500 kHz; this power is then compared to the emission mask value computed for the *center* frequency of the 500 kHz Sub-Band. This method may be performed either by manually summing the measurements or by using a measurement instrument's Band Power Measurement function. It is sufficient to measure a contiguous sequence of twelve 500 kHz windows across each adjacent Channel, plotting the measured value at the center of the 500 kHz Sub-Band window.

The FCC allows a single method to be used for all measurements, or, if desired, one of the above methods may be employed in the 500 kHz window adjacent to each Channel Edge and the other method for all other measurements further from the Channel Edge. The FCC requires that the frequency bin spacing on the measurement test instrument is to be less than or equal to the Resolution Bandwidth as displayed.

Note:

Method 2 is the basis for the measurement procedures given in clause 5 of this document and most of the theory outlined in clause 6. An indirect measurement method also using Method 2 which may prove more useful than in a manufacturing setting is outlined in clause 6. Measurements using Method 1 are specifically allowed by the FCC and may be advantageous for certain automatic systems or measurements controlled by a computer. However, implementation of a suitable procedure and ensuring its conformance to the FCC's regulations is beyond the scope of this document.

4.7 Required Filtering for Some LPTV DTV Transmitters and Translators

To protect the RNSS bands (i.e., Radio Navigational Satellite Service, which is also called Global Positioning System or GPS), the FCC requires that low power DTV transmitters operating on Channels 22-34, Channel 36, Channel 38 and Channels 65-69, exhibit sufficient filtering between the transmitter's power amplifier and its antenna terminals to ensure sufficient suppression of harmonics [FCC 47CFR§74.794(b)].

At least 85 dB of attenuation (with respect to the loss exhibited at the transmitter's fundamental frequency) in the frequency ranges of 1164 MHz to 1215 MHz (Band L5), 1215 MHz to 1240 MHz (Band L2), and 1559 MHz to 1610 MHz (Band L1) is required between the output of the transmitter's power amplifier and the transmitter's antenna output terminals.

5 Measurement Procedures

5.1 General

This section provides the step-by-step procedures necessary to measure 8-VSB transmitter's Near-Channel Emissions using a method that allows direct, in-service (or out-of-service) measurements. Near-Channel Emissions are those that are on either side of and close to the transmitter's Channel (e.g., within approximately a dozen MHz of the Channel's center). Specialized test equipment that automatically makes the required Emissions measurements to the FCC requirements may be used instead of these procedures. If available, use of such equipment will greatly simplify the measurement process.

If automatic equipment is not available, then general purpose test equipment (i.e., spectrum analyzers) may be computer-controlled to make this measurement; or measurements may be made manually. If a computer-controlled general purpose instrument is used, the creation and testing of a program that reliably makes measurements to the requirements of 4.6 is well beyond the scope of this document and is left to the user.

If the measurement is to be performed manually, a procedure using a spectrum analyzer is given below. The approach used is listed as Method 2 of Note 4 in 4.6.5. This approach is used because it requires a limited number of measurements and all required noise bandwidth and detector corrections are automatically made by the band power or channel power algorithms within the test equipment. A band stop filter is employed to obtain the necessary measurement dynamic range while often allowing in-service measurements.

Another, indirect, method is outlined in clause 6 and its use may be advantageous in a manufacturing setting.

5.2 General Measurement Information

Emission measurements are made in a total of 24 Sub-Bands, each 500 kHz wide, on both sides of the transmitter's signal. To facilitate measurements, the Sub-Bands are numbered as shown in Figure 6.

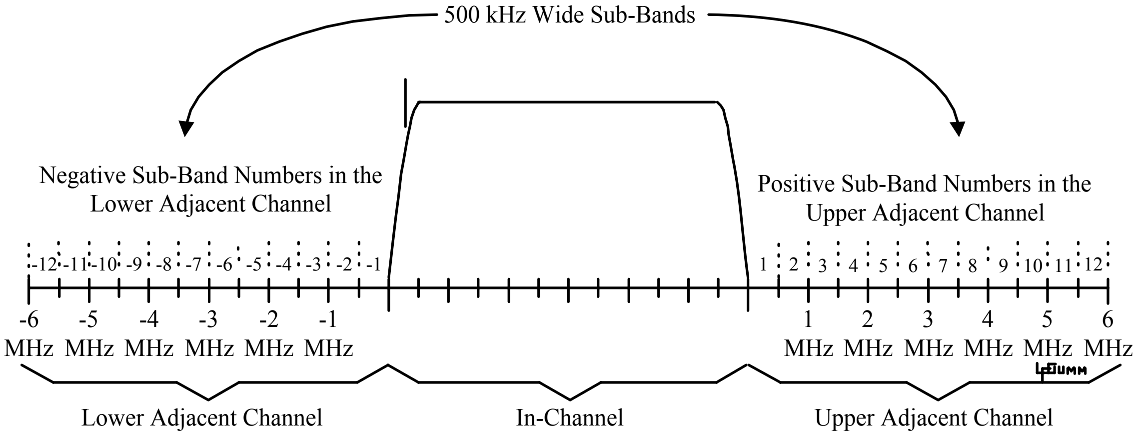

Figure 6—Numbering of the 500 kHz frequency Sub-Bands in the adjacent Frequency Bands next to the transmitter's Channel

The same properly calibrated measurement instrument should be used for all measurements.

A 10 kHz resolution bandwidth is recommended for all measurements except when a 30 kHz bandwidth may be required in 5.5.4(a).

For those familiar with this measurement, an abbreviated version of the step by step procedure is provided in 5.7

5.3 Required Equipment

It is most convenient if the Sampling Devices' output impedance and all of the equipment and connecting cables below have the same nominal characteristic impedance. Otherwise, matching transformers must be used to obtain the high return losses required for accurate measurements. Typically, 50Ω devices are used for emissions measurements.

This procedure requires the following items:

a) Spectrum Analyzer or other measurement instrument:

   Required performance: the difference in amplitude between its specified two-tone Third Order Intercept (i.e., TOI, which is sometimes referred to as IP3) and its internal displayed average noise floor level (DANL) in a 10 kHz measurement shall be ≥110 dB. It must support a 10 kHz measurement (i.e., Resolution) Bandwidth and be capable of measuring total average power within a designated frequency range (i.e., with Band Power or Channel Power markers). This measurement is typically called Band Power Measurement or Channel Power Measurement. While manual corrections are straight forward, measurements are simplified if the instrument automatically corrects Band Power Measurements for errors caused by the proximity of its own noise floor. If the instrument's internal variable input attenuator features a ≤ 5 dB step size, no external step attenuator is required.

b) Band Stop Filter: Required for measuring Full Service Emissions; *sometimes* required for measuring the other two masks. The band stop filter reduces the amplitude of the 8-VSB signal within the transmitter's Channel while leaving the adjacent Channel Emissions more than 2 MHz away from the Channel Edge (relatively) unattenuated. Lowering the amplitude of the in-Channel 8-VSB signal prevents the spectrum analyzer from internally creating intermodulation products that will invalidate the measurement. (*See 6.2*)

   For Full Service measurements with the spectrum analyzer performance given above, the filter should meet the specification given in Figure 18 plus the following: Input power: ≥ 1 Watt and be tuned to the Channel under test. The filter must also be well-shielded to prevent off-air ingress in high field strength locations such as transmitter sites.

   As noted in 6.3.2.2, a reduced attenuation version of the band stop filter is sufficient for measurement of Emissions to the Stringent and the Simple masks. An instrument with a 120 dB difference between its two-tone TOI amplitude and its 10 kHz noise floor (sensitivity) can measure the Simple mask directly.

c) Variable Attenuator: Required *only* if the measurement instrument's internal step attenuator has a minimum step size > 5 dB. Range 0 to ≥ 10 dB (> 60 dB preferable); Power rating: ≥ 1 Watt; Step size ≤ 5 dB; Accuracy: ≤ ±0.3 dB; Flatness over the 18 MHz frequency range centered at the transmitter's frequency: ±0.3 dB. A fixed 5 dB attenuator or two fixed 3 dB attenuators may be used as a substitute for the step attenuator. Fixed attenuators are much less expensive but they require more effort to insert and remove from the signal path.

d) Miscellaneous high quality coaxial cables and adapters as required.

e) 30 dB Fixed Attenuator. Used for protection of the instrument during initial connection of the Sampling Device. ≥ 2 Watt to ≤ 5 Watt rating. Must have connectors suitable for connection between the spectrum analyzer and the cable from the Sampling Device (normally type-N).

5.4 Setting Up the Test Apparatus

5.4.1 Connecting to the Measurement Instrument

At a transmitter site, particularly at a Full Service transmitter, there is always a danger when connecting to the measurement instrument that an unexpectedly high amplitude signal from the Sampling Device will cause damage. If the signal amplitude at the Sampling Device's output port is not known, and no other method to determine its amplitude (i.e., a high-power, power meter) is available, use the following procedure.

A 30 dB attenuator is needed for the process (a 20 dB attenuator may be used but presents a higher risk to the instrument). This attenuator should have a power of 2 Watts to 5 Watts (too large and the heating effect is not significant) rating and its attenuation known to within 1 dB. Its attenuation may be determined to an adequate accuracy by noting how much signal amplitude change it causes when it is inserted between a signal source and the instrument at the transmitter's frequency.

The first step of the process is to connect the attenuator ***only*** to the signal coming from the Sampling Device (i.e., the other port of the attenuator is left open). After connection, monitor the attenuator for an excessive temperature rise (a cautious touch of the hand is all that is necessary). Wait a full minute while continuing to monitor its temperature.

If all appears well, then after adjusting the instrument to its maximum Reference Level and also making sure that its internal attenuator is at its maximum value, connect the attenuator's open port to the instrument's input.

Use the procedure given in 6.1.5 (i.e., add about 12 dB to the pilot signal's amplitude) or 5.5.4 (i.e., measure the signal's amplitude using Band Power markers) to measure the 8-VSB signal's power at the attenuator's output. Determine the estimated total average 8-VSB signal power by adding the attenuators' attenuation value to the measured signal amplitude.

Example:

An inexpensive 2 Watt, 30 dB attenuator with type-N connectors is available. Using an ordinary CW signal generator, and measuring its output amplitude with the instrument before and after the attenuator was inserted in the signal path, it was determined that the attenuator's insertion loss was 31 dB.

After connecting this attenuator to the cable from the Sampling Device, holding the attenuator in the hand revealed only a modest amount of heating.

After adjusting the instrument to a +30 dBm Reference Level with a maximum RF attenuation setting, the attenuator's output was applied to the instrument's input connector. Thus connected, the amplitude of the pilot signal measured in a 10 kHz Resolution

Bandwidth was measured to be -15 dBm. (The use of a 10 kHz Resolution Bandwidth insures that the pilot's amplitude was measured accurately. *(See 6.1.5.)*

The total average power of the 8-VSB signal is then:

$$\begin{gathered}\textit{Total Average 8-VSB Power} \approx \textit{Pilot Amplitude} + \textit{Pilot to Total power Factor} + \\ + \textit{Attenuator Loss}\end{gathered} \qquad (12)$$

$$\textit{Total Average 8-VSB Power} \approx -15\ dBm + 12\ dB + 31\ dB \approx\ +28\ dBm$$

In an unknown transmitter plant it is very possible to encounter a very high output amplitude from a Sampling Device. This is especially true when a new system is first being turned on. In that case the attenuator may be damaged or destroyed. But, all in all, better it than the measurement instrument.

5.4.2 Connecting to the Transmitter

Caution: do not make an actual connection to the measurement instrument without following the procedure given in the preceding sub-clause to qualify the output amplitude of the Sampling Device.

The measurement instrument should be connected as shown in Figure 7 or Figure 8. The required sample of the antenna signal shall be obtained *after* all filtering has been performed (e.g., after any harmonic low-pass or Emission Mask Filters). If available, it is better to operate the transmitter into a dummy load for Emissions measurements. This diminishes the possibility of errors caused by off-air signal ingress but does prevent in-service measurements.

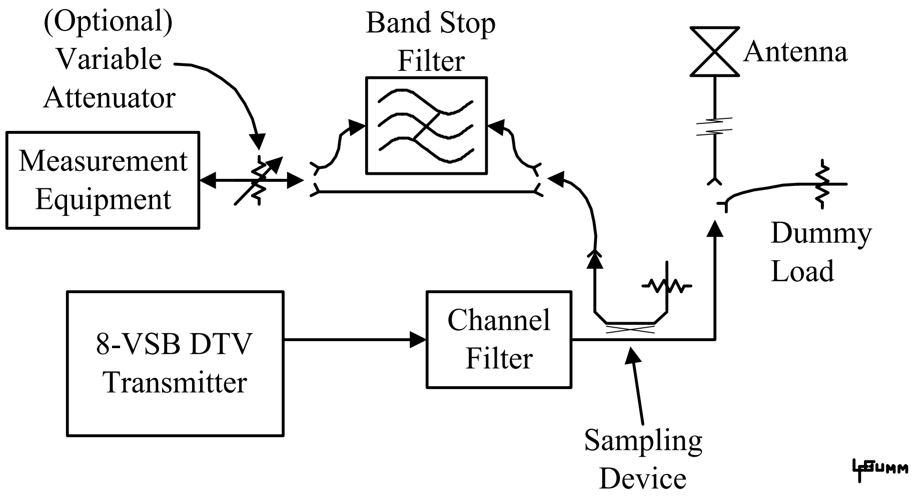

Figure 7−Source of test signal from higher power transmitters

When measuring a Full Service transmitter with a *typical* spectrum analyzer, a total signal amplitude of the 6 MHz 8-VSB signal should be about +27 dBm but no more than +30 dBm. See 6.3.2.1 to determine the minimum power required for the analyzer at hand.

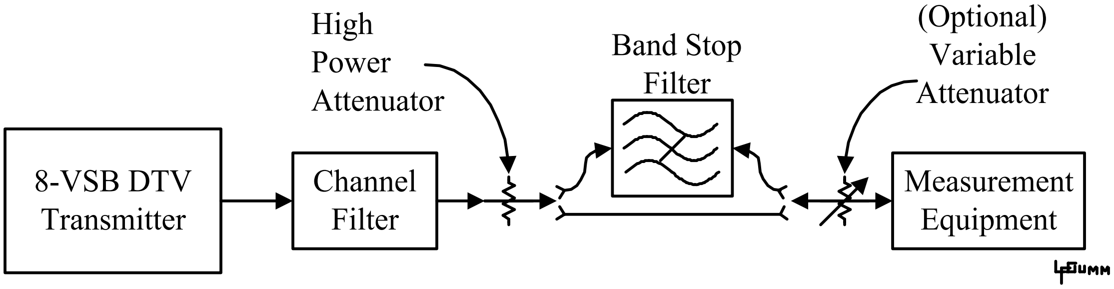

Figure 8−*Optional* sources of test signals for lower power transmitters

To provide reliable results, the Sampling Device should conform to the requirements given in 4.5. It is critical that the test equipment be connected to the Sampling Device's output port using well-shielded transmission lines exhibiting low structural return loss, and that the transmission lines are equipped with high quality connectors known to exhibit very low reflections.

It is good engineering practice to hold flatness errors caused by reflections in the measurement system to ≤ ±0.5 dB. To achieve that goal it is critical that the *sum* of the return loss of the measurement instrument plus the return loss of the Sampling Device be at least 25 dB.

The transmission line connecting the test instrument to the Sampling Device should be of sufficient quality not to contribute reflections of its own. Because of the large total power required to make measurements to the required dynamic range, it is typically not possible to use attenuators to reduce reflections. If there is doubt, return loss measurements with a network analyzer or return loss bridge may be required.

To avoid errors due to ingress of off air signals, the shielding of the entire measurement system must be sufficient. First cap the measurement instrument's input and observe with full sensitivity the spectrum to be measured for signal leakage into that unit. If no leakage into the instrument is observed, a test for sufficient shielding of the interconnecting cables is to leave the cable connected to the measurement instrument and disconnect the cable's source end and terminate it in a matched load. Then re-connect the shell of the cable's *connector* to the shell of the source connector it was removed from.

If the 8-VSB signal from the transmitter under test is thus reduced by 60 dB from its initial value and the signal amplitudes caused by ingress of any nearby transmitters are reduced in amplitude below the measurement instrument's noise floor at full sensitivity (i.e., with no attenuation), the shielding is sufficient for accurate measurements of Near-Channel Emissions. **(Use extreme caution to increase the instrument's input attenuator setting to accept the input signal's full power before reconnecting the cable to its RF source connector.)**

When a band stop filter and/or external attenuator(s) are inserted in the path between the Sampling Device and the measurement instrument, it is important that they, and the cables that connect them, are also well shielded. The cables and the devices may be tested for ingress by connecting the entire system as it is to be used, and then testing each element using a process similar to above. Connect the entire system together and then *individually* disconnect, terminate and ground the end of each cable (i.e. ground the cable's connector to the source connector that it was removed from). By testing each leg of the system while the remainder is still connected, any leakage caused by the devices or their cables should become apparent.

5.5 Detailed Step-by-Step Procedure for Near Channel Emissions

Proceed as follows:

5.5.1 EQUIPMENT CHARACTERIZATION

a) Characterize the measurement instrument. If a VSB analyzer is used, verify that the instrument has the required dynamic range and that the required 8-VSB DTV signal power is available for it.

If a spectrum analyzer is used, determine that its sensitivity in a 10 kHz RBW and its specified TOI (Third Order Intercept) performance are adequate to make the measurements. To make the measurements in this document, the instrument shall exhibit at least a 110 dB range between these two values. For example, an acceptable instrument would exhibit a TOI greater than +10 dBm and exhibit a sensitivity in a 10 kHz RBW of less than -100 dBm.

b) Characterize the band stop filter. Making measurements in the Sub-Bands further from the Channel requires the use of a band stop filter in front of the spectrum analyzer to reduce the amplitude of the in-Channel 8-VSB signal. Before its installation, the filter should be measured to determine its insertion loss at the *center* of each 500 kHz Sub-Band. This filter is very sharply tuned so that small tuning variations caused by temperature changes or aging may cause significant errors if data from past measurements is relied upon. *(See Figure 20)* The easiest way to perform this test is when the measurement instrument includes a built-in tracking generator. Or, an external RF signal generator that covers the transmitter's frequency range may be used.

In either case, determine the amplitude of the signal source at the instrument's input using the same connecting cables that will be used to measure the filter but without the filter in the loop. Then insert the band stop filter and observe the change in attenuation. Carefully determine the filter's loss at the center of Sub-Bands ±4 through ±12. To avoid error due to the slope of the filter's attenuation across any 500 kHz Sub-Band, use only Sub-Bands with a filter attenuation slope of less than 6 dB. *(See Figure 23 and Table 3)*

5.5.2 DETERMINATION OF 8-VSB SIGNAL POWER

a) Determine the total average 8-VSB signal power in the 6 MHz Channel required to make Emissions measurements to the desired mask. *(See 6.3.2.1)* Determine if the amplitude so obtained will be greater than the maximum safe input level of the instrument. If so, use an external attenuator to reduce the signal amplitude to its safe level. Do not forget to increase the power required by the value of the maximum loss exhibited by the band stop filter in Sub-Band ±12.

b) To avoid overload or damage to the measurement instrument, connect it to the transmitter, as in Figure 7 or Figure 8, using the procedures given in 5.4.1. Once connected, *estimate* the total signal power available by adding 12 dB to the measured amplitude of the 8-VSB signal's pilot. Verify that sufficient signal power is available for the measurement. The band stop filter is *not* used in the first set of measurements.

5.5.3 SPECTRUM ANALYZER SET-UP

a) If the instrument does not have an internal attenuator with a ≤ 5 dB step size, then an external attenuator with a ≤ 5 dB step should be inserted in front of the analyzer to allow the mixer input amplitude to be adjusted in finer steps. A variable step attenuator is best but a fixed 5 dB attenuator or two 3 dB attenuators may be inserted as needed in the signal path in lieu of the step attenuator. This approach, while much less expensive, is far more cumbersome.

b) Now find the mixer input amplitude Sweet Spot. Set the instrument for a 10 MHz or 20 MHz span. (*See 6.2 for further information about the Sweet Spot amplitude)*

If an external attenuator is used:

> Insert external attenuation at least equal in value to the step size of the instrument's internal step attenuator. Adjust the instrument to its maximum Reference Level. While observing the 8-VSB signal and its adjacent Channel Emissions on the instrument's screen, reduce the external attenuation in 3 dB or 5 dB steps. Using the information shown in Figure 14, watch for a change in *slope* in the sideband Emissions in the 3rd or 4th Sub-Band indicating the presence of the instrument's own intermodulation products. *(See Figure 15)* Once the external attenuator is completely removed, reinsert the attenuation to its beginning value and reduce the instrument's internal RF attenuator one step. Again reduce the external RF attenuation step by step. Repeat until the change of slope indicative of the analyzer's own intermodulation is observed. Then reverse the adjustment sequence until the change of slope has been moved to a point where it is just below the instrument's noise floor.
>
> (If fixed external attenuators are used, a faster method is to initially omit the external attenuation and reduce the instrument's internal attenuation step by step until the instrument's own intermodulation is observed. Then increase the instrument's internal attenuation 1 step and begin the procedure in the paragraph above.)

If the instrument has a ≤5 dB step size internal attenuator:

> Adjust the instrument so that its Reference Level will remain constant as the internal RF attenuator is varied. Starting with a maximum RF attenuation setting, reduce the RF attenuator one step at a time while observing the amplitude of the signal about 2 to 3 MHz above and below the 8-VSB signal's Channel Edges. Adjust the RF attenuation so that the signal's amplitude is *minimized* in this range.

If it is unclear what exact setting to use, it's better that the instrument's mixer input amplitude be slightly too small rather than slightly too large.

5.5.4 MEASUREMENT OF CHANNEL POWER

a) Select a 10 MHz Span. Care shall be taken to ensure that there are sufficient points in the display so that there is less than one Resolution Bandwidth between each frequency display point. In other words, the number of display points must be greater than the span divided by the RBW.

Thus, if the instrument allows selection of the number of display or sweep points, select at least 1001 points for a 10 kHz Resolution Bandwidth and a 10 MHz Span. If the instrument does not allow this particular selection, it shall use more than 1001 points to display a 10 MHz Span, using a 10 kHz Resolution Bandwidth. A 30 kHz Resolution bandwidth may be used if the analyzer has at least 334 points.

b) Use the instrument's Channel Power (Band Power) markers to accurately measure the *total* average signal power in the 6 MHz Channel occupied by the transmitter's signal. Place one measurement limit at the lower Channel Edge and the other limit at the upper

Channel Edge and enable the Band Power Measurement system. Use the detector and video bandwidth setting recommended by the analyzer's manufacturer for maximum accuracy. This typically is either no video filter or a wide video filter setting and a RMS (preferred) or sampling detector setting. If available, a mode that averages the numerical Channel Power results obtained over many measurements or sweeps (i.e., ensemble average) is useful in achieving stable and accurate readings. The result should be an amplitude in dBm.

Some instruments have more than one method or mode of making Band Power measurements. Regardless of what method or mode is selected, to avoid error, use the *same* mode to make all the Emissions measurements in this entire procedure.

5.5.5 MEASUREMENT OF NEAR-CHANNEL EMISSIONS

a) Begin measuring the Near-Channel Emissions. Do not change either the Reference Level or any internal or external RF attenuator setting from the Sweet Spot. Select a 2 MHz Span and tune the instrument to roughly center the 500 kHz Sub-Band being measured. Select a 10 kHz Resolution Bandwidth and use the same Band Power mode and detector and video bandwidth settings as before. Measure the total average power, in dBm, in Sub-Bands ±1, ±2, ±3 and ±4. Do this by selecting the measurement limits for each Sub-Band and enabling the Band Power markers. *(See Table 1)*

   If the instrument does not automatically perform noise proximity corrections, remove the signal input from the analyzer and terminate the analyzer's input in its characteristic impedance. Determine the amplitude of the instrument's noise floor as measured in a 500 kHz bandwidth using the Band Power markers. If the one or more of the signal amplitudes measured in the 500 kHz Sub-Band is within 10 dB of the instrument's noise floor, manually correct the measured amplitudes using the procedure given in 6.2.8. Since all other corrections change the relationship of the signal's amplitude with respect to the instrument's noise floor, this correction must be performed ***before*** any other corrections are made. If the measured amplitude is < 3 dB above the analyzer's noise floor, it is recommended that the measured value be replaced with the instrument's noise floor's amplitude *(See 6.2.8)*.

b) Correct the measured 6 MHz in-Channel 8-VSB total average power and 500 kHz Sub-Band amplitudes by *adding* the value of any external attenuator used *(See 6.2.7)*.

Sub-Band	Lower and Upper Sub-Band Center Frequencies (with respect to the Channel's edge) (All measurements are 500 kHz wide)	
1	-0.250 MHz	0.250 MHz
2	-0.750 MHz	0.750 MHz
3	-1.250 MHz	1.250 MHz
4	-1.750 MHz	1.750 MHz
5	-2.250 MHz	2.250 MHz
6	-2.750 MHz	2.750 MHz
7	-3.250 MHz	3.250 MHz

8	-3.750 MHz	3.750 MHz
9	-4.250 MHz	4.250 MHz
10	-4.750 MHz	4.750 MHz
11	-5.250 MHz	5.250 MHz
12	-5.750 MHz	5.750 MHz

Table 1—Sub-Band center frequencies

c) Insert the band stop filter in the signal path as shown in Figure 7 or Figure 8. Because the filter sharply reduces the in-Channel amplitude of the 8-VSB signal, the attenuation in the signal path may now be significantly reduced thus increasing spectrum analyzer's sensitivity and allowing Emissions in the higher Sub-Bands (i.e., further from the Channel Edge) to be measured to the full sensitivity required for verification of the mask. *(See 6.3.2.3)* Reduce the external (if used) or internal attenuation while observing the measured response following the same external-internal sequence as before (in Step f) until a new Sweet Spot amplitude is found or, as is typically the case, until all attenuation is removed This provides the best (optimum) situation for measuring Emissions in the remaining Sub-Bands.

d) Using the frequency data given in Table 1, measure the Emissions in Sub-Bands ±4 and all of the yet unmeasured Sub-Bands and correct for the proximity of the instrument's noise floor as required. *(See 6.2.8)*

e) Correct the measured 500 kHz Sub-Band amplitudes by *adding* the value of any external attenuator. *(See 6.2.7)*

f) Correct the data taken for the Sub-Band measured with the band stop filter by *adding* the filter's insertion loss measured at the center of that Sub-Band.

g) The amplitude of the Emissions in units of dB_{DTV} in a given Sub-Band is now computed by *subtracting* the measured total average power of the 8-VSB signal in the 6 MHz Channel (in dBm) from the (corrected) measured 500 kHz Sub-Band power (in dBm). The result is the value of the Emissions in that Sub-Band in dB_{DTV}. *(See 5.6)*

h) *If possible*, compare the Emissions measured in Sub-Band ±4 with and without the filter as a check on the validity of the measurement process.

5.5.6 COMPARISON OF MEASURED VALUES TO EMISSION MASK

Compare the computed value of Sub-Band Amplitude with the values given in Table 2 for the appropriate mask for the transmitter under test to verify FCC emission mask compliance.

Sub-Band	Full Service	Stringent	Simple
1	-47.0 dB_{DTV}	-47.0 dB_{DTV}	-46. dB_{DTV}
2	-49.9 dB_{DTV}	-49.9 dB_{DTV}	-46.4 dB_{DTV}
3	-55.6 dB_{DTV}	-55.6 dB_{DTV}	-47.1 dB_{DTV}
4	-61.4 dB_{DTV}	-61.4 dB_{DTV}	-48.1 dB_{DTV}
5	-67.1 dB_{DTV}	-67.1 dB_{DTV}	-49.5 dB_{DTV}
6	-71.9 dB_{DTV}	-71.9 dB_{DTV}	-51.3 dB_{DTV}

7	-78.6 dB_{DTV}	-76 dB_{DTV}	-53.3 dB_{DTV}
8	-84.4 dB_{DTV}	-76 dB_{DTV}	-55.8 dB_{DTV}
9	-90.1 dB_{DTV}	-76 dB_{DTV}	-58.5 dB_{DTV}
10	-95.9 dB_{DTV}	-76 dB_{DTV}	-61.7 dB_{DTV}
11	-101.6 dB_{DTV}	-76 dB_{DTV}	-65.1 dB_{DTV}
12	-107.4 dB_{DTV}	-76 dB_{DTV}	-69.0 dB_{DTV}

Table 2— Allowable emission amplitudes for a given Sub-Band

See 5.6 for an example of computing the correct Emissions amplitude from the measured data.

5.6 Example of Computations

Example:

To show how the measurement values are obtained and utilized, the Emissions for Sub-Band -12 of a Full Service transmitter will be determined. Assume the transmitter was measured with the following results:

a) Band stop filter measurement:
   1) Measured loss of the stop band filter at the midpoint of Sub-Band -12: 0.7 dB

b) Measured without the band stop filter:
   1) External attenuator when the mixer input amplitude is set to the analyzer’s Sweet Spot: 3 dB
   2) Total average power of the 8-VSB signal in the 6 MHz Channel as measured by the instrument using its Band Power markers (i.e., w/o correcting for the external attenuator): +26.9 dBm

c) Measured with the band stop filter in the signal path:
   1) Attenuation of external attenuator when the mixer amplitude is set to the analyzer’s Sweet Spot using the filter: 2 dB
   2) Removing the 8-VSB signal from the analyzer’s input terminals and terminating the analyzer’s input, the amplitude of the instruments noise floor in 500 kHz: -83.1 dBm
   3) Total measured Sub-Band Emissions using the instrument’s band power markers to measure the power in the 500 kHz wide Sub-Band -12 (i.e., the reading as taken w/o any corrections applied): -79.9 dBm

Computation:

> Note: It is good engineering practice is to perform these calculations to the nearest 0.1 dB to control round off error, then round the final result to the nearest integer dB_{DTV} to more closely reflect the measurement’s actual accuracy. Even with great care, the final result, which is made over a wide dynamic range and requires so many steps and corrections, will have an uncertainty of ±1 dB to ±2 dB.

a) The total average input power is the total signal as directly measured by the instrument plus the value of the *external* attenuator:

Total Average Input Power = Instrument's Measured Value + External Attenuator Setting. (13)

Total Average Input Power = +26.9 dBm + 3 dB = +29.9 dBm

b) Using the Sub-Band -12 data, the correction for the proximity of the instrument's noise floor *must* be performed first as the other corrections will alter the relationship between the measured value and the amplitude of the noise floor.

$$Noise\ Corrected\ \ Amplitude = 10\log\left(10^{\frac{Measured\ sub\ band\ power}{10}} - 10^{\frac{Measured\ noise\ floor\ power}{10}}\right) \quad (14)$$

$$Noise\ Corrected\ \ Amplitude = 10\log\left(10^{\frac{-79.9}{10}} - 10^{\frac{-83.1}{10}}\right) = -82.7\text{dBm}$$

c) The total Emissions measured in Sub-Band -12, is the value measured directly by the instrument plus the value of the *external* attenuator and plus the stop band filter exhibits in the Sub-Band:

Total measured Sub-Band Emissions = Noise corrected amplitude + External Attenuator Setting + Filter Loss in Sub-Band -12: (15)

Total Sub-Band -12 Emissions = (-82.7 dBm) + 2 dB + 0.7 = -80.0 dBm

d) Converting to dB_{DTV}:

Sub-Band Amplitude dB_{DTV} *= Total Sub-Band Emissions – Total Average Signal Power* (16)

Sub-Band -12 Amplitude dB_{DTV} = (-80.0 dBm) – (+29.9 dBm) = -109.9 dB_{DTV}

Sub-Band -12 Amplitude $\text{dB}_{\text{DTV}} \approx$ -110 dB_{DTV}

e) From Table 2, at the midpoint in Sub-Band 12, a Full Service transmitter's Emissions shall be less than -107.4 dB_{DTV}. This transmitter is nicely below the Full Service mask in Sub-Band -12. However, the process of correcting for noise floor proximity results in small variations of measured power causing larger variations in calculated results. It is good engineering practice to average multiple readings if the measured Emissions are near the mask limit.

Measurement to the Stringent and the Simple masks is similar. Depending on the test instrument used, the band stop filter may not be required for measurements to the Simple mask (this can easily be determined by calculating the amplitude, in dB_{DTV} of the instrument's noise floor after it is adjusted to its Sweet Spot before the band stop filter is inserted in the signal path). And, of course, the appropriate column in Table 2 shall be used to determine the correct value of allowable Emissions.

5.7 Summary Outline of Step-by-Step Procedure

For those familiar with the process, the key elements of the procedure are:

a) Characterize the measurement instrument. If a spectrum analyzer is used, measure its DANL (noise floor) performance and obtain its TOI specifications.

b) Measure the band stop filter's insertion loss at the *midpoint* of Sub-Bands ±4 to ±12.

c) Make sure that sufficient 8-VSB signal is available from the test point to make the measurements for the intended mask. Be sure to include the band stop filter's maximum loss in Sub-Band ±12 when calculating the required signal power.

d) Make measurements *without* the band stop filter. After carefully adjusting the signal amplitude applied to the instrument's mixer to find its Sweet Spot amplitude, measure the total signal power as well as the Emissions in Sub-Bands ±1, ±2, ±3 and ±4.

e) Correct these readings for proximity to the instrument's noise floor (as needed). If needed, this must be done *before* any other corrections are made or before the data is used for any purpose.

f) Correct the resulting amplitude for any *external* attenuator used.

g) Insert the band stop filter in the signal path and again adjust the signal amplitude at the mixer input to a new Sweet Spot amplitude.

h) Measure the remaining 500 kHz Sub-Bands that haven't yet been measured. If feasible, re-measure Sub-Bands ±4 for comparison with those made without the band stop filter.

i) Correct these readings for proximity to the instrument's noise floor (as needed). If needed, this must be done before any other corrections are made or before the data is use for any purpose.

j) Correct for the value of any *external* attenuation used.

k) Correct the sub-measurements made with the band stop filter for the filter's insertion loss.

l) Compute the amplitude of the Emissions in dB_{DTV} by subtracting the total average power (in dBm/6 MHz) from the measured Sub-Band Emissions (in dBm/500 kHz).

m) Check the results obtained with the mask values in Table 2, each at the midpoint of the 500 kHz Sub-Bands.

6 Essential Theory and Background Required for 8-VSB Spectral Measurements

6.1 Spectral Measurement Background and Theory

6.1.1 Noise Bandwidth Concept

With the exception of the pilot carrier, the 8-VSB signal is “noise-like”. This means that for measurement purposes, the 8-VSB signal has characteristics similar to a spectrally-shaped source of Gaussian (or Johnson) noise. A property of flat Gaussian noise is that measured average noise power is proportional to the *noise* bandwidth of the device used to make the measurement.

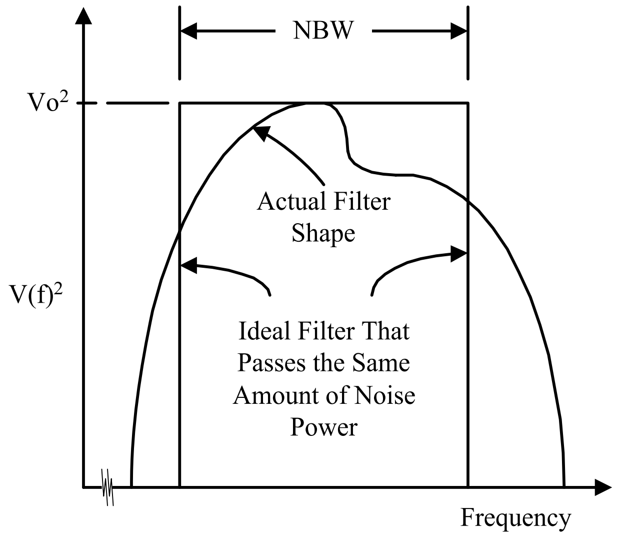

Figure 9–Illustration of noise bandwidth

A filter’s noise bandwidth is defined as the width of a rectangular or ideal *flat* frequency response that has the same peak amplitude and passes the same amount of noise power as the actual filter. This concept is shown in Figure 9. Mathematically, noise bandwidth is [B4]:

$$\mathrm{NBW} = \frac{1}{V_o^2}\int_0^{\infty} (V(F))^2 \, dF \tag{17}$$

where

NBW = noise bandwidth

V(F) = The ***voltage*** versus frequency characteristic of the filter or signal being measured

Vo = The peak ***voltage*** response of the filter or signal

When the amplitude of a flat spectrum noise (or noise-like) signal is measured using a filter with a known noise bandwidth, the results can then be expressed or *scaled* as if the measurement were made using a different noise bandwidth (assuming the noise is spectrally flat over the largest bandwidth under consideration). This is accomplished by multiplying the measured power by the ratio of the ***noise*** bandwidths. For instance, to express a measurement made using a 10 kHz noise bandwidth in terms of a 500 kHz noise bandwidth, multiply the power in the 10 kHz bandwidth by the ratio of the bandwidths.

$$P_{500\mathrm{kHz}} = \mathrm{P}_{10\mathrm{kHz}}\left(\frac{500\mathrm{kHz}}{10\mathrm{kHz}}\right) \qquad (18)$$

Or, in logarithmic terms of dB or dBm,

$$\mathrm{P}_{\mathrm{dBm}_{500\,\mathrm{kHz}}} = \mathrm{P}_{\mathrm{dBm}_{10\,\mathrm{kHz}}} + 10\log\left(\frac{500\mathrm{kHz}}{10\mathrm{kHz}}\right) = \mathrm{P}_{\mathrm{dBm}_{10\mathrm{kHz}}} + 17.0\mathrm{dB} \qquad (19)$$

Other measurement bandwidths can be similarly used. For example, if a 30 kHz instead of a 10 kHz noise bandwidth is used, 12.2 dB is added to the readings to convert to a 500 kHz noise bandwidth.

6.1.2 Measurement Detail Versus Resolution Bandwidth

When measurements are made over the *non*-flat portions of the 8-VSB signal (e.g., the steep root-raised-cosine transition regions at the Channel Edges), excessive Resolution Bandwidth causes errors. An attempt to use a 300 kHz or a 500 kHz measurement filter is similar to drawing a graph with a wide pen; when the signal amplitude changes rapidly with frequency, detail is lost. Further, measured values in the transition region and near adjacent Channel region are well above the correct amplitude, showing the transmitter as *apparently* failing to meet the FCC's regulations.

Narrower bandwidths are typically used to make out-of-Channel Emissions measurements. The readings are then scaled to a 500 kHz bandwidth as required by the FCC rules. ***A Resolution Bandwidth of 10 kHz is recommended for all measurements of the 8-VSB signals in this document.***

6.1.3 Noise Characteristics of the 8-VSB Signal

The 8-VSB signal is designed to be noise-like. This fact, combined with knowledge of its equivalent noise bandwidth, enables calculating the signal's amplitude when it is measured in a different noise bandwidth. The signal's noise bandwidth may be mathematically calculated by placing equation (1) into the integral in equation (17). However, its value can be determined virtually by inspection. The ***voltage*** response at each edge of the 8-VSB Channel is a *root*-raised-cosine function (similar to a sine function operating between 0 and $\pi/2$). When squared to create a ***power*** spectrum, a raised-cosine function is obtained (similar to a raised-sine function operating between $-\pi/2$ and $\pi/2$). (*See Figure 10*)

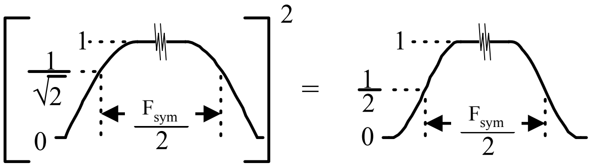

Figure 10−Squaring the 8-VSB transmitter voltage function to obtain a ***power*** vs. frequency function

Noise bandwidth is defined as an ideal or rectangular filter with the same area and same peak amplitude as the voltage squared (i.e., ***power***) response. The voltage-squared response is shown at the left in Figure 11. The sine portions of the curve are hatched. Because the sine curves are symmetric about the half-power frequencies, the raised-sine curve at the right can be inverted and set on top of the raised sine curve at the left to create a square box with the same area as the voltage squared curve. This is shown at the right.

By inspection, the width of this square box is ½F_{symbol} or 5.381 MHz, which is the ***equivalent*** noise bandwidth of the 8-VSB signal.

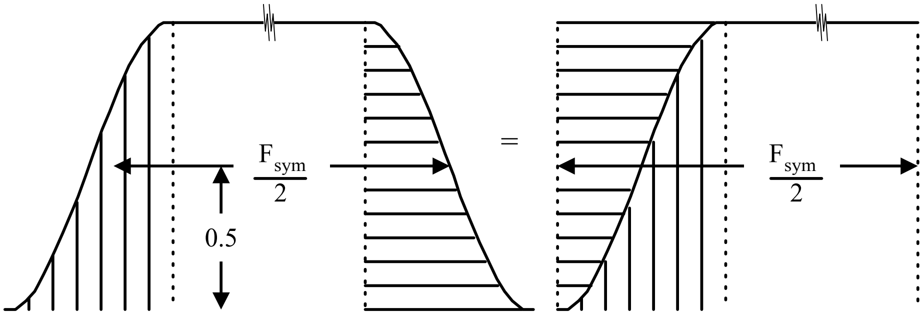

Figure 11−Determining the 8-VSB transmitter's equivalent noise bandwidth

6.1.4 Amplitude of the Pilot Signal

The pilot signal is specified to be -11.3 dB in amplitude with respect to the average data signal power [B2].

6.1.5 dB$_{DTV}$ Amplitude Of An Ideal 8-VSB Signal

The 8-VSB signal contains both the data signal and the pilot signal. If the pilot signal is -11.3 below the amplitude of the average 8-VSB data signal, then taking the 8-VSB data signal to be 0 dB, the average power of the total 8-VSB signal with respect to the data signal is:

$$\textit{Total Average Signal Power} = 10\log\left(1+10^{\frac{-11.3}{10}}\right) = 0.31\,dB \text{ w.r.t. the 8-VSB data signal} \quad (20)$$

Conversely, it follows that removing the pilot signal from the *total* 8-VSB signal, leaving only the average data signal reduces that signal's amplitude by 0.31 dB. Starting with that fact and changing from a 5.381 MHz to a 500 kHz bandwidth, to express the amplitude of the data signal in dB$_{DTV}$,

$$\textit{Data Signal Power}\Big|_{500\text{kHz BW}} = -0.31\text{dB}_C + 10\log\left(\frac{0.500\text{MHz}}{5.381\text{MHz}}\right) = -10.63\text{dB}_{DTV} \quad (21)$$

That is, a display of the 8-VSB DTV signal scaled for display in dB$_{DTV}$ will show the Head or the flat central portion of an ideal 8-VSB DTV signal to be –10.63 dB$_{DTV}$ in amplitude (i.e., the Head, when measured in a 500 kHz bandwidth, will be 10.63 dB below the total average in-Channel power in 6 MHz).

Further, if removing the pilot signal causes a 0.31 dB reduction of power of the 8-VSB signal, then taking the entire 8-VSB signal to be 0 dB, the power of the pilot signal is:

$$\text{Pilot Signal} = 10\log\left[1-10^{\frac{-0.31}{10}}\right] = -11.62\text{dB}_c \text{ w.r.t the total 8-VSB signal power} \quad (22)$$

That is, the amplitude of the pilot is 11.6 dB *below* the total average signal power. Thus, if the 8-VSB signal exhibits good flatness across its Frequency Band and reasonably accurate root-raised-cosine transition regions, its total power can be *estimated* by adding 11.6 dB to the measured amplitude of its pilot signal. (A Resolution Bandwidth of 30 kHz or less should be used to measure the pilot's amplitude to keep the power of the surrounding 8-VSB signal (i.e., noise-like digital sidebands) from affecting the results.

6.2 Instrumentation Limitations

6.2.1 Instrument Topology

Measuring the 8-VSB signal's Emissions to the FCC's limits requires that the spectrum analyzer's ability to measure small signals in the presence of large ones (i.e., its dynamic range) be pushed very close to its limit. To do so, it is important for the user to understand a small amount about the internal topology of spectrum analyzers. While there is a large variation in detail between various vendors and even between various models of a given vendor's product line, Figure 12 is sufficiently accurate to provide the required insight to allow operating the unit effectively.

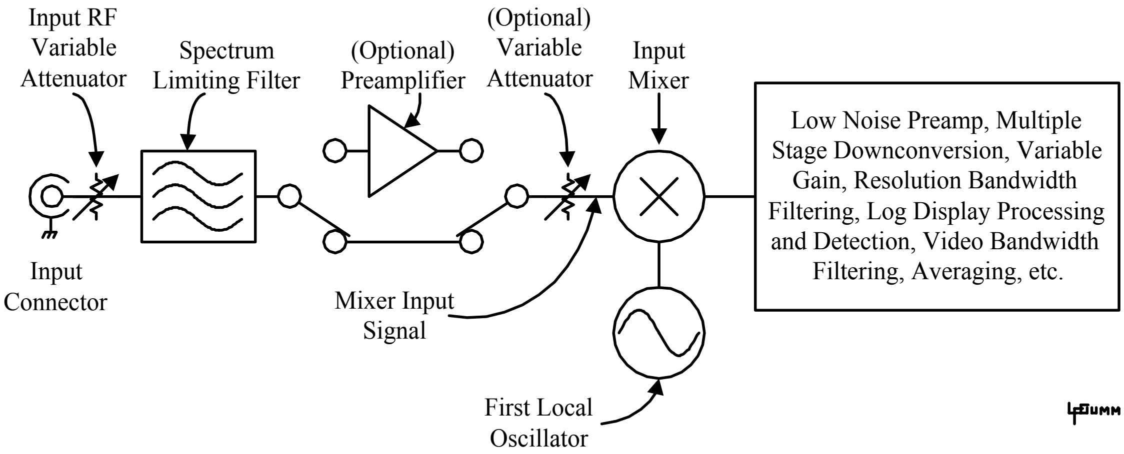

Figure 12—Typical Spectrum Analyzer input topology.

From the input connector, the signal is almost always first routed to an input RF attenuator. From there it goes to some form of filter to eliminate signals from unwanted portions of the spectrum that cause spurious responses (e.g., from image frequencies). This is typically a low pass filter but may be a band pass filter in the higher frequency bands of microwave spectrum analyzers.

After the filter, there is often, but not always, a preamplifier that may be switched in to improve the instrument's sensitivity. While switching it into the signal path improves the instrument's overall sensitivity by many dB, because of this preamplifier's linearity and noise figure limitations, the instrument's overall *dynamic range* is always reduced. Therefore the use of a preamp is ***not*** recommended for any 8-VSB Emissions mask measurements. For that reason, a preamp is not used in any of the procedures in this document.

A second variable attenuator may follow the preamplifier, followed in turn by the analyzer's input mixer. (The exact arrangement of how the preamplifier is placed with respect to the variable attenuator(s) varies a good deal between models and vendors but does not matter since the preamplifier's use isn't recommended). The maximum signal amplitude that the analyzer can effectively measure is typically determined by small non-linearities in this mixer. *(See 6.2.2)* Further, the minimum signal that the analyzer can measure is determined by this mixer's loss combined with the noise figure of the receiver system following it.

As the instrument's Reference Level Control is varied, the instrument automatically performs a sequence of adjustments of the variable input RF attenuator and the IF gain (following the input mixer). If the instrument has been adjusted to a low Reference Level value (e.g., -60 dBm), the instrument will set the RF attenuator to a low or zero value and increase the IF gain to bring signals of that amplitude to the top of the screen. As the Reference level is increased to higher values, the IF gain is first reduced until it's at an optimum value to maximize the instrument's displayed dynamic range. Then as the Reference level is further increased, the instrument will normally insert RF attenuation in front of the input mixer instead of lowering the IF gain further. This is done to prevent the application of large signal amplitudes to the input mixer that could cause intermodulation distortion.

Dynamic range is the amplitude difference between the maximum signal amplitude that the mixer can accommodate without significant distortion and the amplitude of the instrument's noise floor referred the mixer's input. A spectrum analyzer will typically exhibit its best dynamic range when a 10 dB/div display mode is selected and the Reference level is adjusted to the largest value before the RF attenuator's setting is increased. The instrument will exhibit this same dynamic range when its RF attenuator is inserted in the signal path, but the optimum amplitude range will be higher by the amount of the attenuation.

6.2.2 Effects of Intermodulation within the Measurement Equipment

The maximum signal that may be applied to the input mixer of a spectrum analyzer without distortion is determined by the instrument's intermodulation capability. When two signals are simultaneously applied to the analyzer's input, intermodulation creates more than two responses in its display. The extra responses are called spurious responses or intermodulation products.

For Near-Channel 8-VSB measurements, third-order intermodulation is the controlling intermodulation problem. Third-order intermodulation is typically characterized in terms of its two-tone Third Order Intercept (TOI or IP3), measured in dBm. TOI is measured by applying two, *equal*-amplitude CW signals to the instrument separated by a small frequency difference, typically 1 MHz or 2 MHz. As the amplitude of the two signals is increased toward the top of the instrument's dynamic window, two more (spurious) signals will appear flanking (i.e., above and below in frequency) the original signals but separated from them by the same frequency difference that separates the original signals. Because these intermodulation products are created by the second harmonic of one of the signals minus the fundamental of the other, they are termed third order. As shown in Figure 13, a property of third order intermodulation products is that their amplitude increases at a 3:1 rate with respect to the fundamental's amplitude. This means that as the amplitude of the two CW signals are increased, starting at a low amplitude (carefully keeping them equal in amplitude), at first no intermodulation products will be visible. Then, once a critical amplitude is reached, the intermodulation products will suddenly appear out of the instrument's noise floor and quickly become much larger with further amplitude increases.

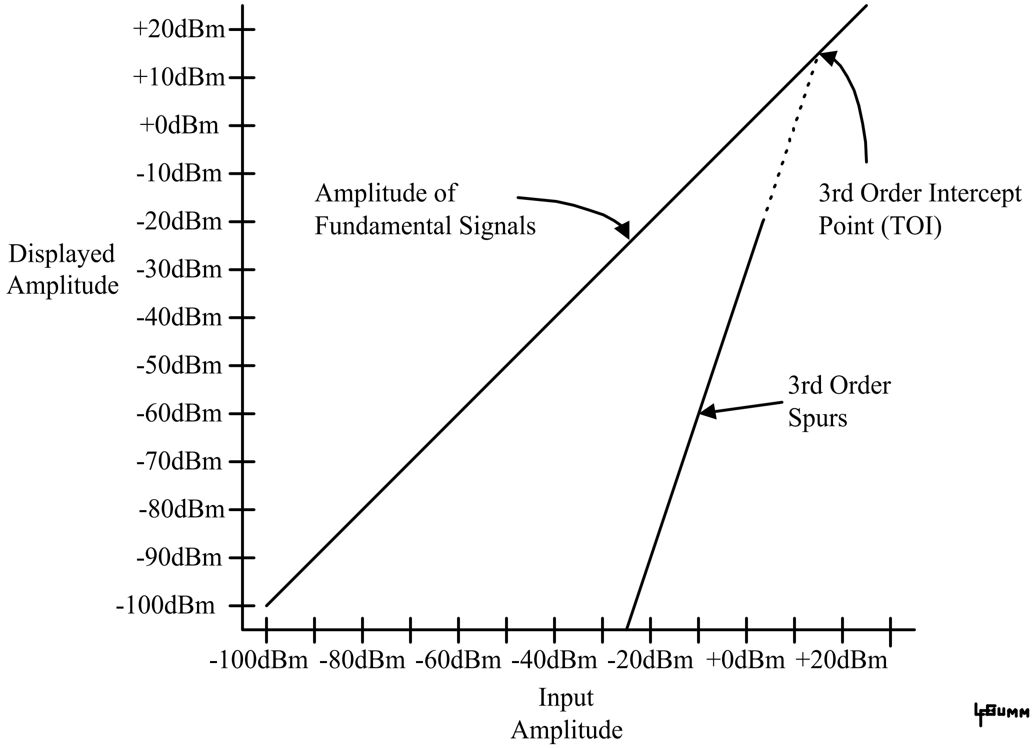

Figure 13—Intermodulation Amplitude Vs. Input Amplitude

TOI is the extrapolated input amplitude that would cause the amplitude of each of the fundamental signals to equal the amplitude of their third order intermodulation products. Since the intermodulation product's amplitude *increases* at a 3:1 rate, in dB, with respect to the amplitude of the CW signals, the *amplitude difference* between them *decreases* at a 2:1 rate. TOI is easily computed by doubling the amplitude difference between the CW signal and its intermodulation product and adding this value to the amplitude of the CW signal.

Like other third order intermodulation products, the Shoulder amplitude of the 8-VSB signal increases 3 dB for every dB increase of the *total* average 8-VSB signal power. Or, viewed another way, the amplitude difference between the Shoulder and the Head *decreases* 2 dB for every dB *increase* in 8-VSB amplitude.

Because the observed amplitude of the 8-VSB signal changes with measurement bandwidth while the amplitude difference between the signal's Head and Shoulder does not, it is convenient to think of the instrument's intermodulation performance in terms of its Head-to-Shoulder intercept amplitude (e.g., its 8-VSB HSI). That is, HSI represents (by extrapolation) the total average 8-VSB signal amplitude that would cause the amplitude of the VSB signal's Shoulder to equal the Head's amplitude.

A spectrum analyzer's TOI is almost always specified. For TOI to be useful to determine the analyzer's performance when measuring 8-VSB signals, the relationship between it and the corresponding Shoulder amplitude caused by the instrument's intermodulation on an 8-VSB signal must be known. After careful measurement of several modern spectrum analyzers, it has been determined that a spectrum analyzer's 8-VSB HSI is *about 3 dB lower* (i.e., from 2 dB to 4 dB) in amplitude than its TOI. *(See Annex A).*

The TOI performance of various spectrum analyzer models varies a good deal. Lower performance models may have a guaranteed TOI of only +5 dBm while a high performance model may have a guaranteed TOI of +22 dBm. An instrument's *typical* (i.e., not guaranteed) TOI is sometimes also given and is always greater than the guaranteed value. **The curves and illustrations below assume that the instrument used has a TOI of +10 dBm,** a value slightly poorer than specified by most mid-range spectrum analyzers**.**

6.2.3 Instrument Sensitivity Limitations

Most measurement receivers, such as spectrum analyzers, are designed to maximize their dynamic range; that is, to maximize the amplitude difference between a maximum amplitude determined by creation of visible spurious intermodulation products and a minimum amplitude determined by the instrument's internally generated noise. Because they are optimized for dynamic range, they often exhibit a startlingly high internal noise floor when compared with other receivers.

The sensitivity of spectrum analyzers also varies between high and lower performance models. Lower performance models often exhibit a displayed average noise level (DANL) of -102 dBm to -107 dBm in a 10 kHz Resolution Bandwidth (without preamp). Higher performance models often exhibit values less than -110 dBm.

6.2.4 Combined Effects of Intermodulation and Sensitivity

To successfully make 8-VSB Emissions measurements, it is critical that the measurement instrument used has a sufficient dynamic window between its intermodulation limitations which limit how large of a signal may be applied to its mixer input, and its internal noise floor that limits how small a signal may be measured by it. In this document, dynamic range is defined by the amplitude difference between the instrument's specified TOI amplitude and its displayed noise in a 10 kHz Resolution bandwidth. Commonly available instruments have dynamic ranges, so defined, from 108 dB to 140 dB. **To use the step-by-step procedure in clause 5, it is critical that the instrument used exhibit a dynamic range of at least 110 dB.**

Once a suitable instrument is obtained, the optimum signal amplitude to apply to its input mixer must be found. If too much signal power is applied to the input mixer of a RF measurement instrument, it creates internally-generated intermodulation products that roughly have a quadratic spectral shape similar to the Simple emission mask. Therefore, these Emissions can *appear* to be emanating from the transmitter under test causing the transmitters emissions to appear too large. However, if too little signal is applied, the instrument's spectrally flat noise floor will mask the transmitter's Emissions, also causing the transmitter's emissions to appear too large.

Therefore, finding the optimum mixer input amplitude, or its "Sweet Spot", is important to enable effective measurement of the transmitter's Emissions.

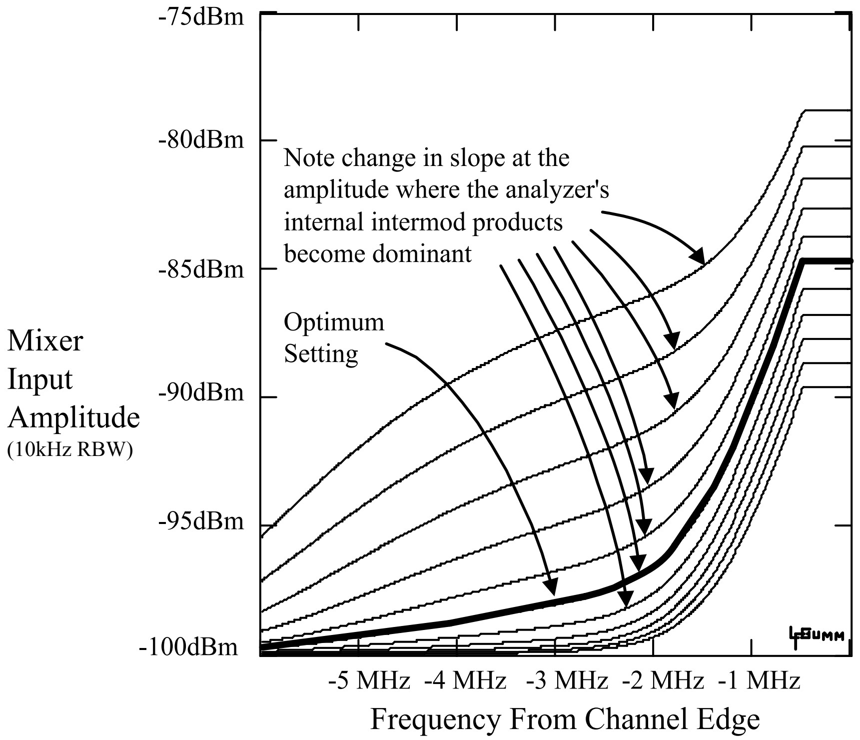

Figure 14—Simulated spectrum analyzer display as the 8-VSB signal is increased in 1 dB steps at the mixer's input terminals.

The effect that the instrument's internally created intermodulation and its noise floor have on the measurement process as amplitude of the 8-VSB signal is varied is shown in Figure 14. This figure was created by simulation but correctly shows the effect of the input signal at the input mixer increasing in 1 dB amplitude steps from 5 dB below the Sweet Spot to 5 dB above.

The lower adjacent Channel of an 8-VSB signal is shown. The lower Channel Edge is at the extreme right. The first 500 kHz of the display shows the Shoulder of the transmitter's response. The amplitude of the Emissions starts falling beyond 500 kHz from the Channel's edge. This figure assumes the transmitter's Emissions are being shaped by a Full Service or Stringent transmitter's Channel Filter (or Emission Mask Filter).

The figure assumes that an *external* 1 dB step attenuator is being used to change the signal's amplitude because there is a corresponding 1 dB change in the amplitude of the Emissions at the transmitter's Shoulder with each change in attenuation[5].

The lowest response is obtained with the lowest amplitude applied to the mixer or with the maximum attenuation in the signal path. As the amplitude increases through the first three or four 1-dB steps, the signal rises out of the noise floor with little increase in the amplitude of the noise floor itself. At about the fifth attenuator step, the amplitude of the instrument's intermodulation has increased to the point that it is above the instrument's

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[5] If an attenuator *internal* to the spectrum analyzer were being used, and only the RF attenuator (i.e., not the Reference Level) were being changed, the analyzer, to present the correct display, would offset the display. Thus the shoulder's amplitude on screen would not change but the amplitude of the noise floor would change instead.

noise floor. As the amplitude increases from the 5th through the 10th dB step, the instrument's intermodulation rapidly increases in amplitude and becomes dominant.

6.2.5 Finding the Sweet Spot for Full Service and Stringent Mask Transmitters

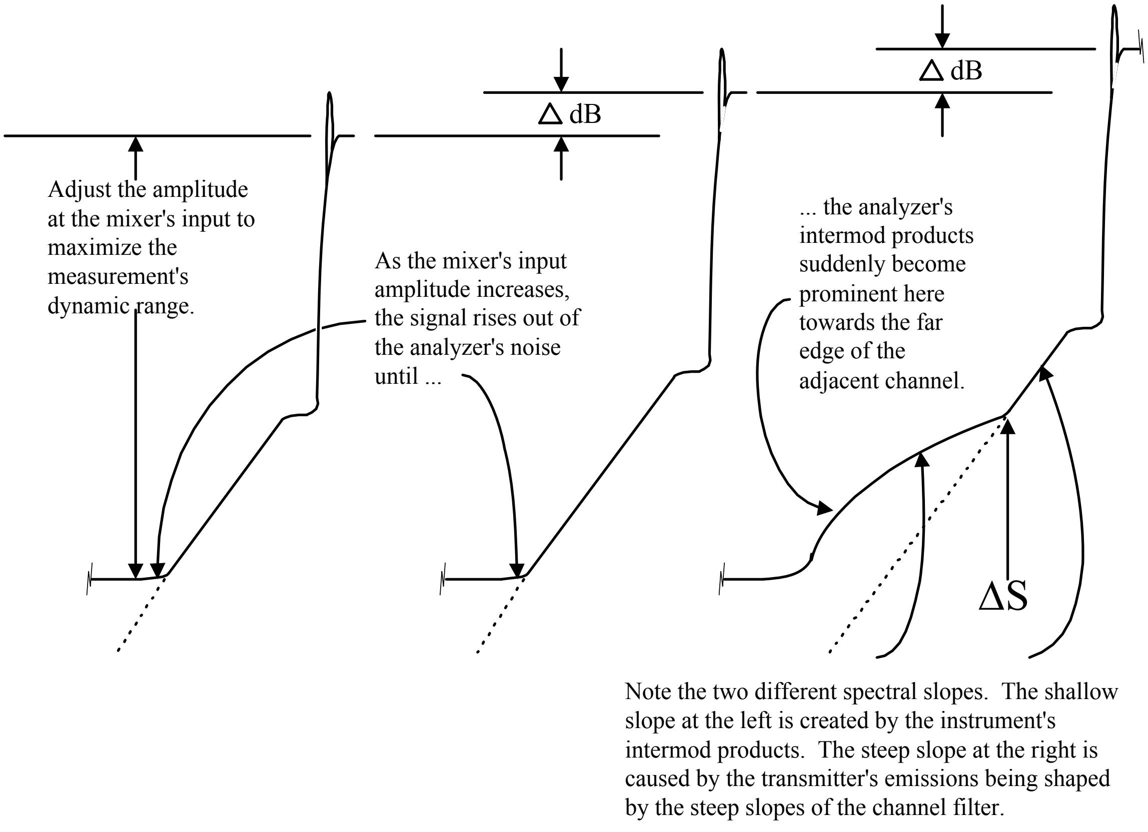
The goal when adjusting the signal amplitude at the input mixer is to find the "Sweet Spot", or the amplitude that maximizes the difference between the emission levels at the 500 kHz "Shoulder" and the Emissions at 2 MHz into the adjacent Channel. Examination of the data used to create Figure 14 and practical experience gained in the field indicates that an error of ±2.5 dB in setting the Sweet Spot's amplitude will result in a loss of only about 1.5 dB of the instrument's dynamic range. Therefore, an instrument featuring a 5 dB step size internal RF attenuator will allow the adjustment to the Sweet Spot amplitude with only a small loss of measuring ability. The reduction of dynamic range is faster if the amplitude error results in the amplitude at the mixer being too high; so when in doubt, err on the side of a low-amplitude setting (i.e., larger input attenuation). It has been found that changing the amplitude in somewhat larger steps (3 dB or 5 dB) allows easier determination of the "Sweet Spot".

With the help of Figure 15 (and Figure 14), plus a little experimentation and experience, measurement instruments such as spectrum analyzers can be easily adjusted to the Sweet Spot. At Figure 15(a), the 8-VSB signal is too small. The analyzer's intermodulation products are well below the instrument's noise floor and less of the 8-VSB signal is visible above the noise floor than is optimum (i.e. the dynamic range is less than optimum).

At Figure 15(b), the 8-VSB signal power into the instrument has been increased a small amount. The intermodulation products have increased at a three times rate and are unseen but are about equal to the instrument's noise floor. This is the optimum input signal amplitude. At this amplitude, the instrument will display the widest dynamic range it is capable of.

At Figure 15(c) the amplitude of the 8-VSB signal has been increased yet again. Here, the analyzer's intermodulation products have risen in amplitude above its noise floor causing a slope change in the response where the intermodulation products are about the same amplitude as the transmitter's Emissions. Since these products rise at a 3:1 rate for changes in the 8-VSB signal amplitude, they will quickly reduce the measurement's dynamic range.

When testing Full Service and Stringent mask transmitters, many observers have found that it is relatively easy to pick out the variation of slope. Figure 15(c) "ΔS" marks the point along the response where the amplitude of the instrument's intermodulation products is equal to the transmitter's Emissions. To the right of the arrow pointing to "ΔS" in Figure 15(c), the displayed Emissions are primarily coming from the transmitter. To the left of point "ΔS", the displayed Emissions are primarily created within the measurement instrument itself.



(a) (b) (c)

Figure 15−Effects of intermodulation distortion and noise floor.

Note: At (a), the 8-VSB signal amplitude at the input mixer too low, at (b) the amplitude at the input mixer is at optimum and at (c) the amplitude at the input mixer is too high.

And finally, some spectrum analyzers internally detect when excessive signal has been applied to its input with an on screen overload indicator. With these analyzers, the “Sweet Spot” may be found relatively easily by adjusting the instrument to lower and lower Reference Level settings until the overload indicator is activated. The “Sweet Spot” is obtained when the Reference Level is then increased to just turn off the indicator.

6.2.6 Finding the Sweet Spot for Simple Mask Transmitters

Finding the Sweet Spot is more difficult when measuring transmitters using the Simple mask because the shape of the transmitter’s Emissions is similar to the instrument’s internally-created intermodulation products. One way to find the Sweet Spot is to use the instrument’s delta measurement marker system, placing the reference marker on the Head or flat portion of the 8-VSB signal’s Emissions and the other marker at a point about 2 MHz from the Channel Edge. The signal amplitude at the mixer input is then slowly increased by either changing the instrument’s internal RF attenuator or an attenuator external to the instrument while observing the amplitude difference between the markers. Use averaging or heavy video filtering to reduce the measurement to measurement variations. The Sweet Spot is the mixer input amplitude that maximizes the amplitude difference between the two markers.

This measurement is easier to perform if the instrument can be adjusted to allow the reference marker in the delta marker measurement mode to *track* the signal's amplitude at a given frequency. Otherwise, finding the Sweet Spot with this method is tedious.

This technique may also be used to find the Sweet Spot for measurements to a Full Service or Stringent mask, but experience has shown that with these two masks it is faster and easier to increase the signal amplitude while looking for a slope variation and then after finding it, to reduce the mixer's input amplitude to move its amplitude down to the instrument's noise floor.

Since the Simple emission mask requires the least amount of dynamic range of all the masks, some spectrum analyzers can measure Emissions to this level without a two-step process requiring a band stop filter. In these situations, a 5-dB *internal* step attenuator can be used to minimize the Emissions at the far side of the adjacent Channel by visual inspection.

If the spectrum analyzer has an internal overload detection system, the Sweet Spot can be found by lowering the Reference Level setting until the indicator just turns on and then increasing the setting until it just turns off again.

Remember that the goal is not to precisely determine the actual amplitude of the transmitter's Emissions, but rather to verify that the Emissions in any given Sub-Band are below the FCC's emission mask and within compliance. While finding the Sweet Spot is occasionally difficult and frustrating, it should be kept in mind that any errors that are made will cause the Emissions to appear to be too *large*. Therefore, **if a measurement shows the transmitter to be in compliance, it most probably is,** regardless if the Sweet Spot amplitude was correct or incorrect.

6.2.7 Correcting Reference Level and Measurement Values for External Attenuation

When a spectrum analyzer's input attenuator is used to control the signal amplitude at its input mixer, the analyzer compensates for this and displays the signal at the correct point on screen and similarly corrects all marker amplitudes. However, when an *external* attenuator is used ahead of the instrument, the on-screen readout and marker amplitudes must be (mentally) modified by the user to reach the correct value. If an external attenuator is inserted in front of an instrument, its Reference Level or marker amplitude must be corrected by *adding* the external attenuation value to the Reference Level.

Example:

The instrument's Band Power markers have been used to determine that the Emissions in a 500 kHz Sub-Band is -44 dBm. An external 5 dB attenuator was inserted in the signal path in order to position the mixer input signal at the Sweet Spot amplitude. What is the Corrected Measured Amplitude?

$$\textit{Corrected Measured Amplitude} = 5\text{ dB} + (-44\text{ dBm}) = -39\text{ dBm} \tag{23}$$

6.2.8 Noise Floor Proximity

6.2.8.1 Amplitude Correction at a Single Frequency

Measurements made within 10 dB of the measurement instrument's noise floor should be corrected because the instrument's noise appears in the measurement bandwidth simultaneously with the transmitter's Emissions, causing the measured power of the Emissions to be too large. For instance, if the Emissions are only 7 dB above the instrument's noise floor, their measured value will be about 1 dB larger than the Emissions' true value because inclusion of the instrument's noise.

Some instruments can be adjusted to automatically correct measurements made for this effect. If automatic corrections are not available, then manual corrections can be made using this procedure. It's easiest to describe the procedure using an example:

Example:

A spectrum analyzer's marker system is used to measure the amplitude of the transmitter's Emissions. The reading obtained was -100.6 dBm. Removing the transmitter's signal from the analyzer's input and repeating the measurement to obtain the amplitude of the instrument's residual noise floor yields a value of -104.2 dBm[6]. What is the signal's correct amplitude?

The instrument's noise floor is subtracted from the desired signal by converting the two logarithmic dBm readings to linear power values, subtracting the power of the residual noise floor from the total measured power, then converting the remaining power back into dBm.

The corrected reading is then [B5][7]:

$$\text{Corrected Reading} = 10\log\left[10^{\frac{-100.6\text{dBm}}{10}} - 10^{\frac{-104.2\text{dBm}}{10}}\right] = -103.1\,\text{dBm} \qquad (24)$$

Great care must be taken when the signal-plus-noise amplitude approaches the noise amplitude. For example, a well-averaged amplitude reading of a noise or the noise-like 8-VSB signal is likely to have a measured amplitude uncertainty of perhaps ± 1 dB. When the average amplitudes of the Emissions-plus-noise and the noise are approximately 3 dB apart, each with a ±1 dB uncertainty, then the error in the Corrected Reading could be as great as +1.3 dB to -1.8 dB. Because only a few measurements will be taken in any realistic Emissions testing procedure, this large measurement error, with its bias toward understating the true amplitude of the transmitter's Emissions may create undesirable problems.

To deal with this source of error, **it recommended that when the Emissions-plus-noise and the noise amplitudes are within 3 dB of each other, that the noise amplitude be used as the Corrected Reading**. That is, when the values are within 3 dB, the noise proximity correction calculation is omitted and the measured amplitude of the instrument's noise floor becomes the Emissions amplitude for this Sub-Band. When this done, the amount of error is reduced to a window of -1 dB to +2.3 dB with respect to the Emissions' true amplitude. Thus, the amount of the error is reduced and the error is biased in a conservative direction of slightly *overstating* the true Emissions amplitude.

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[6] To be theoretically correct, after the signal source is removed , the analyzer's input should be re-terminated in the same source impedance presented by the signal source (in this case, 50 Ω). However, it almost never makes a difference. Observe to see if the instrument's noise floor varies with and without the termination. If it does not, then a termination is not necessary. In high field environments the input connector may require being terminated in a load to prevent off-air pickup when the signal cable is disconnected.

[7] This procedure is correct when measuring noise or noise-like signals like 8-VSB Emissions. It is only *approximately* correct when measuring coherent signals like sine waves near the instrument's noise floor.[B4]

If, after substituting the measured noise floor amplitude, the transmitter's Emissions are below the mask, because of the conservative nature of the substitution, there is a strong presumption that the transmitter's Emissions are, indeed, less than the mask. If, however, after using this technique the transmitter does not meet the mask's limits, and yet there is doubt that its Emissions exceeds the mask, then the situation may be resolved by making multiple measurements of both the Emissions-plus-noise and the noise amplitudes. The results are then averaged to reduce the measurement uncertainty before attempting the noise floor proximity correction calculation. Many instruments may be adjusted to perform this process automatically (e.g., RMS detector modes and ensemble averaging).

If performed manually, the averaging process must be performed similarly by exponentiating each dB value, averaging the resulting power values and then finding the average's dB value. Good engineering judgment as to the number of measurements required and to the reliability of the results must be applied.

6.2.8.2 Correction of Band Power Measurements

The same procedure may be used when power within a frequency *range* is measured using the instrument's Band Power or Channel power mode. This algorithm has been carefully designed by the instrument's manufacturer to determine the total power in the selected interval, typically by making multiple measurements across the desired frequency range, and summing the results while applying appropriate corrections at each stage of the process. If measured in log mode, each measured value is mathematically converted from a logarithmic power value (dBm) into an equivalent linear power value (e.g. mW); then the power values are summed to obtain the total power within the frequency range and, if required, the result is then converted back into an equivalent dBm value.

Focusing on the process of summing the power:

$$Total\ Power = \sum M_n = \sum_n (S_n + N_n) = \sum_n S_n + \sum_n N_n \tag{25}$$

where

M_n = the value of the power measured by the nth measurement within its bandwidth at the frequency of the measurement

S_n = the power of the desired signal included in the nth measurement

N_n = the power of the analyzer's noise floor included in the nth measurement

That is, the resulting value of measured power is a summation of individual measurements and each individual measured value can be thought of as consisting of the sum of the desired signal's power plus the unwanted power from the instrument's noise floor. The *shape* of the spectrum of the desired signal within the range where the measurements are taken is *irrelevant*; all that matters is the value of the summation across the interval. Similarly, the shape of the noise across the interval (normally reasonably flat) does not matter.

When the signal is removed and the measurement repeated the result is:

$$\text{Residual Noise} = \sum_{\text{n}} \text{N}_{\text{n}} \tag{26}$$

Therefore, the value of the signal portion of the total power can be readily calculated as:

$$\text{Signal Power} = \text{Total Power - Residual Noise Power} = \sum_n M_n - \sum_n N_n \qquad (27)$$

Or:

$$\mathit{Signal\ Power\ (dBm)} = 10\ \log\left(10^{\frac{\mathit{TotalPower\ (dbm)}}{10}} - 10^{\frac{\mathrm{Re}\,\mathit{situal\ Noise\ Power\ (dbm)}}{10}} \right) \qquad (28)$$

This is exactly the same process that is used for single point measurements. Therefore the procedure for correcting Band Power measurements for noise proximity is also exactly the same.

It is also recommended that when the Emissions-plus-noise and the noise amplitudes measured using Band Power or Channel Power modes are within 3 dB of each other, that the measured noise amplitude be used as the Corrected Reading. *(See 6.2.8.1)*

6.3 Measuring Near-Channel Emissions

6.3.1 General Approaches

There are two general approaches to measuring 8-VSB Emissions to the Full Service mask.

The first, which is the preferred method, is to use a band stop filter to lower the amplitude of the 8-VSB in-Channel signal in order to allow the *direct* measurement of its low amplitude near-Channel Emissions. The theory and background information required to understand this approach is given in 6.3.2. The step-by-step procedure for this approach is given in 5.5.

The second approach is an *indirect* measurement of the 8-VSB signal's Out-of-Channel Emissions by making measurements of the transmitter's Emissions before and after the transmitter's own Channel (Emissions mask) Filter. In effect, the transmitter's filter is used to raise the amplitude of the low amplitude out-of-Channel Emissions with respect to the 8VSB signal. The two sets of data are then combined mathematically to infer their amplitude. The theory and background information required to understand this approach is given in 6.3.3 but no step by step procedure is provided in this document.

6.3.2 Measurements Using a Band Stop Filter

This method allows the direct measurement of the 8-VSB transmitter's Emissions from a sample of the signal taken from the transmitter's output. The step-by-step procedure given in section 5 uses this procedure. The in-Channel average power of the 8-VSB signal and the Emissions of the first few 500-kHz Sub-Bands near the transmitter's Channel are first measured with a direct connection from the Sampling Device to the measurement instrument. Then a band stop filter is interposed between the Sampling Device and the measurement instrument in order to reduce the amplitude of the in-Channel 8-VSB signal at the instrument's terminals, thus allowing the instrument's sensitivity to be increased without creating internally-generated Emissions within the instrument. It can then measure the low amplitude out-of-Channel Emissions without a problem.

The development below is presented to show how the theory behind the measurement process. **For simplicity, the Sub-Band ±12 loss of the stop band filter is assumed to be zero.** To compensate, the instrument's noise floor used below was assumed to be -100 dBm in a 10 kHz Resolution Bandwidth. This value is about 3 dB greater (i.e., worse) than the sensitivity exhibited by almost all mid range spectrum analyzers.

6.3.2.1 Minimum 8-VSB Test Signal Amplitude

For a moment, assume that a ***mythical*** measurement instrument is available; one that is capable of measuring the full dynamic range (110 dB_{DTV}) of the Full Service mask. (Later, such an instrument will be, in effect, concocted by making multiple measurements and using a band stop filter.) The question is, then, what is the minimum in-Channel 8-VSB signal amplitude that must be applied to this mythical instrument so that the low-amplitude Emissions specified by the various masks are just equal to the instrument's noise floor? The calculation for a Full Service transmitter is shown in Figure 16.

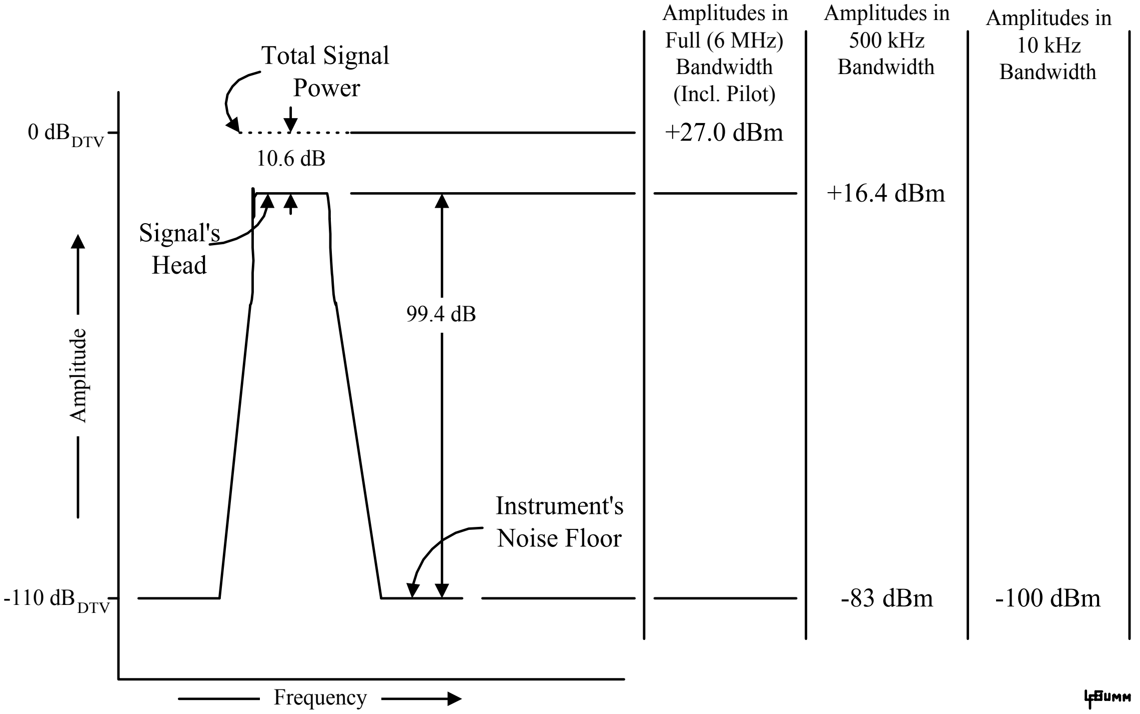

Figure 16—Determining the minimum 8-VSB signal amplitude required to be able to measure a Full Service transmitter.

The starting point is that the assumed mythical instrument's measured sensitivity is -100 dBm in a 10 kHz bandwidth. To assure that any Emissions at the Full Service mask's limit (-110 dB_{DTV}) may be accurately measured, there must be sufficient signal applied to the analyzer to bring these Emissions just to the instrument's noise floor.[8] This enables measurements to determine mask compliance but may not allow the actual emissions amplitude to be determined if it is well below the mask.

Since the signals involved in these measurements are either actually noise or are derived from the noise-like 8-VSB signal, this amplitude can be scaled to a new bandwidth. *(See 6.1.1)* For convenience, the instrument's -100 dBm, 10 kHz Resolution Bandwidth noise floor (shown in the right column) is rescaled to the 500 kHz bandwidth used by the FCC,

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[8] It is *assumed* that noise floor proximity corrections will be employed, either automatically or manually (see 6.2.8), when making Emissions measurements near (i.e. within 10dB) the instrument's noise floor. This allows the total power required to make the measurements to be minimized while simultaneously allowing measurements that will accurately determine if the transmitter *meets* the required emission mask. The degree to which the transmitter's performance *exceeds* the mask's requirements will be less well known.

or -83 dBm (shown in the center column). The Head of the 8-VSB signal is known to be -10.6 dB_{DTV} or 99.4 dB greater than the lower limit of the Full Service mask, so it must be at least +16.4 dBm in amplitude (again, in a 500 kHz bandwidth). Finally, the total signal power in a 6 MHz bandwidth is 10.6 dB greater than that of 8-VSB signal's Head in a 500 kHz bandwidth or at least +27 dBm (shown in the left column). This is the minimum total average signal power required by this mythical instrument to measure the Full Service mask. Or more simply, the minimum required 8-VSB signal amplitude (i.e., +27 dBm in 6 MHz) is 110 dB above the instrument's noise floor when expressed in a 500 kHz bandwidth (i.e., -83 dBm). This is, of course, the 110 dB_{DTV} measurement as defined in 4.6

More generally, to measure a Full Service transmitter, the 8-VSB signal amplitude (in 6 MHz) shall be at least 127 dB greater than the measurement instrument's 10 kHz resolution bandwidth noise floor. A similar calculation may be performed for the Stringent and Simple masks to find that the signal shall be at least 93 dB or 88 dB, respectively, greater than the instrument's 10 kHz bandwidth equivalent noise floor. Therefore, the required power for an instrument with a -100 dBm sensitivity in a 10 kHz bandwidth to measure the Full Service, Stringent, and the Simple masks is +27 dBm, -7 dBm and -12 dBm, respectively.

These are the *minimum* signal amplitudes that must be applied to the mythical instrument in order to measure the low amplitude Emissions at the edge of the various masks. However, as described in 6.2.1, in real instruments, this input sensitivity is achieved by removing all attenuation in front of its input mixer. Further, as described in 6.2.2, applying these large signal amplitudes without attenuation will hopelessly overload that mixer if not destroy it. To use a real instrument to measure the low emission amplitudes required by the mask requires that the 8-VSB signal's in-Channel amplitude be lowered while leaving its near-Channel Emissions in the adjacent Channels unattenuated. This is accomplished using a band stop filter.

Note: The value of required signal power to make measurements determined in this section *assumed* a lossless band stop filter. The maximum amount of loss exhibited by the band stop filter in Sub-Bands ±12 must be added to the signal power calculated above so that sufficient signal will be available at the instruments input after the stop band filter to accomplish the measurements.

6.3.2.2 Band Stop Filter Specifications

The first step in determining the specifications required for the band stop filter is to determine how much of the frequency range near the transmitter's signal may be measured by ordinary instruments *without* using the band stop filter.

To create this example, a "typical" spectrum analyzer is assumed. This analyzer has a +7 dBm 8-VSB HSI (i.e., a +10 dBm two-tone TOI) and a -100 dBm|10kHz RBW sensitivity. These specifications are a bit *poorer* than typical mid-performance spectrum analyzers. Figure 17 shows the results when the 8-VSB signal's amplitude applied to this "typical" analyzer has been carefully adjusted to its Sweet Spot; that is, the 8-VSB signal's amplitude at the analyzer's mixer has been adjusted so that the analyzer can measure to its maximum dynamic range.

To ease the always confusing issues about amplitudes vs. bandwidths in 8-VSB measurements, various amplitudes are given as calculated for three different bandwidths in the columns to the right in Figure 17. Except the value given for the instrument's noise floor, values in the 6 MHz bandwidth column include *all* of the signal power (i.e., both data and pilot together, as measured in a power meter). Values in the 500 kHz column are those that will be obtained when the readings being made are measured with a 500 kHz Band Power marker or are scaled to the 500 kHz bandwidth used in the FCC's regulations. And finally, the 10 kHz column shows the values that will be read directly off of the instrument when using a 10 kHz bandwidth. Keep in mind that all of these amplitudes are referenced to the analyzer's *mixer input*. If any internal input attenuation is used, (typically, there will be 35 to 55 dB of input attenuation used during the measurements *without* the band stop filter, depending on the analyzer) the analyzer's readout will show the amplitudes applied to the analyzer's inputs, not to its mixer.

In the drawing, the signal amplitude is just lower than the analyzer's Sweet Spot; that is, the instrument's internally-created intermodulation products are just equal to its internal noise floor at the Channel edge, not in Sub-Band 4. The spectral *shape* of these products is similar to that of the Simple mask, gradually decreasing in amplitude as they move away from the Channel edge. The fact that the internally-generated Emissions roll-off at increased frequencies from the Channel Edge provides some margin for the band stop filter specifications.

As shown, the "typical" spectrum analyzer will be able to measure Emissions to the FCC's mask just a bit more than 2 MHz from the Channel edge (or Sub-Bands ±1 to ±4) and to an amplitude of about -63 dB_{DTV}. That is, by employing corrections for noise floor proximity, **the first four 500 kHz Sub-Bands can be measured without the band stop filter**.

Examining Figure 17 also provides a guide for calculating the dB_{DTV} measurement capability for actual spectrum analyzers. Because the Head-to-Shoulder amplitude difference decreases at 2:1 with increases in the total average 8-VSB signal power, the optimum value of total average 8-VSB signal power applied to the instrument is 2/3rds of the way from the instrument's 5.4 MHz[9] noise floor and its HSI amplitude. For every 3 dB increase in this amplitude difference (e.g., due to improved analyzer TOI or noise floor specs), there will be a 2 dB increase in the number of dB_{DTV} that may be directly measured. The following equations may be used to estimate a given instrument's expected performance or to calculate about where the "Sweet Spot" amplitude will be found.

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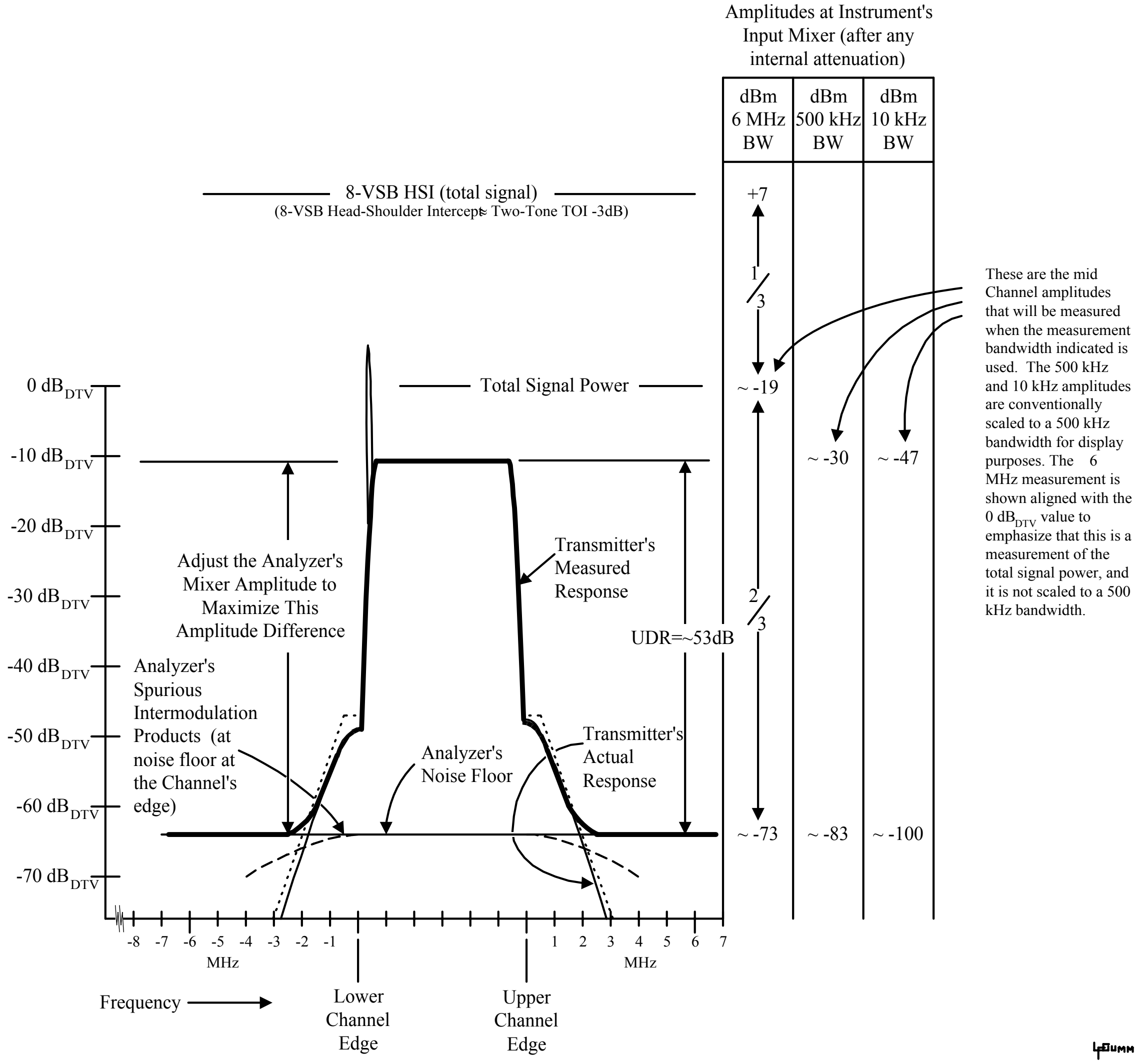
[9] i.e., the 8-VSB signal's equivalent noise bandwidth.



These are the mid Channel amplitudes that will be measured when the measurement bandwidth indicated is used. The 500 kHz and 10 kHz amplitudes are conventionally scaled to a 500 kHz bandwidth for display purposes. The 6 MHz measurement is shown aligned with the 0 dB$_{DTV}$ value to emphasize that this is a measurement of the total signal power, and it is not scaled to a 500 kHz bandwidth.

Figure 17—The amplitude relationships required to maximize dynamic range while measuring the *high* amplitude portion of the 8-VSB spectrum.

Note: (The drawing depicts the 8-VSB signals as measured in a 10 kHz bandwidth).[10]

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[10] The amplitude difference between the tip of the pilot signal and the Head of the 8-VSB signal is a function of measurement (noise) bandwidth. The amplitude difference D is given as DdB= 56 – 10log(measurement noise bandwidth). The pilot's amplitude is shown correctly for a 10 kHz measurement bandwidth even though it appears strange that it is apparently larger than the total signal amplitude. This is an artifact of the amplitude scaling process where the apparent amplitude of the 8-VSB signal's Head varies with bandwidth but the amplitude of the pilot signal does not. If the measurement bandwidth was actually increased, the pilot would shrink with respect to the Head's amplitude until it would essentially disappear at a measurement bandwidth of 500 kHz.

The usable dynamic range (UDR), which is the amplitude difference between the Head and the instrument's noise floor, is:

$$UDR = \frac{2}{3}\left(\left(8\text{-}VSB\ HSI\right) - 5.38MHz\ Noise\right) = \frac{2}{3}\left(HSI - 10\log\left(\frac{5.38\text{MHz}}{10\text{kHz}}\right) - 10kHz\ Noise\right) \quad (29)$$

$$UDR = \frac{2}{3}\left(HSI - 27.3\text{dB} - 10kHz\ Noise\right) = \frac{2}{3}\left(HSI - 10kHz\ Noise\right) - 18.2\text{dB} \quad (30)$$

In terms of dB_{DTV}, the amplitude of the signal's Head is always -10.6 dB_{DTV}. Therefore, the limiting sensitivity or the ability of the instrument to measure will then be UDR dB below -10.6 dB_{DTV}. That is, the instrument's measuring capability, in dB_{DTV}, is -10.6 dB_{DTV} minus UDR dB. This results in:

$$dB_{DTV} Meas.\ Capability = -10.6 - \left(\frac{2}{3}\left(HSI - 10kHz\ Noise, \text{dBm}\right) - 18.2\right)\text{dB}_{\text{DTV}} \quad (31)$$

$$dB_{DTV}\ Meas.\ Capability \approx 8 - \frac{2}{3}\left(HSI - 10kHz\ Noise, \text{dbm}\right)\text{dB}_{\text{DTV}} \quad (32)$$

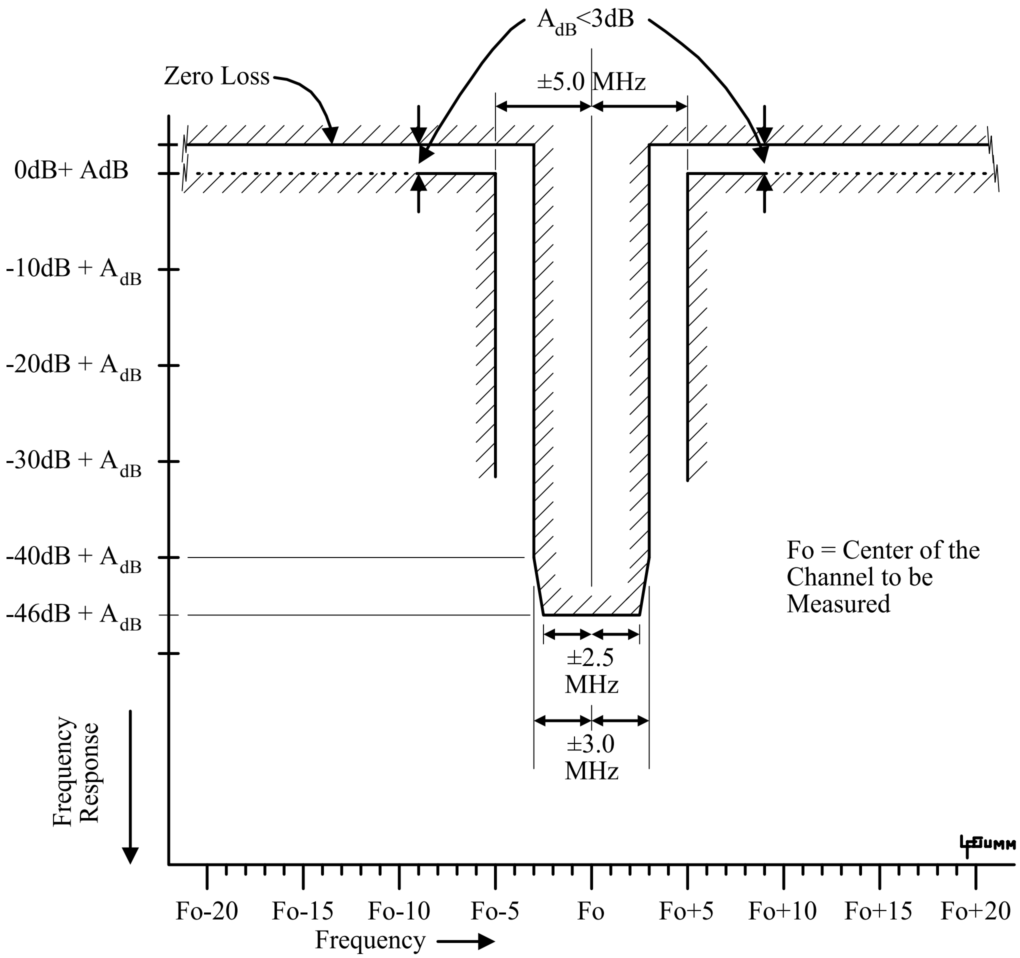
$$dB_{DTV} Meas.\ Capability \approx 8 - \frac{2}{3}\left(\left(\text{TOI} - 3\right) - 10\text{kHz Noise}\right)\text{dB}_{\text{DTV}} \quad (33)$$

Since *direct* measurement of the 8-VSB Near Channel Emissions may only be made to about 2 MHz from the Channel edge before the Emissions are "lost" into the instrument's noise floor, measurement of the remaining frequency range beyond 2 MHz requires use of a stop band filter. It must pass all signals with little or no attenuation 2 MHz beyond the Channel edge while significantly attenuating the 8-VSB signal within the transmitter's frequency Channel. This reduction of the 8-VSB's in-Channel signal amplitude allows the instrument to be readjusted for much greater sensitivity to make the rest of the Emissions measurements.

Figure 16 shows that the total average signal power required to measure a Full Service transmitter to -110 dB_{DTV} is +27 dBm, assuming that the analyzer's noise floor is -100 dBm in a 10 kHz Resolution Bandwidth and a zero loss band stop filter. Figure 17 shows that for the intermodulation signals to be equal to or less than the analyzer noise floor, the total average 8-VSB signal power must be no greater than about -19 dBm at the analyzer's mixer input. The band stop filter must therefore provide

$$+27\ \text{dBm} - (-19\ \text{dBm}) = 46\ \text{dB} \quad (34)$$

of total signal attenuation for the in-Channel 8-VSB signal.



Note: The Attenuation at the edge of the pass band can be any value, A dB up to 3dB at Fo ±9 MHz. However, the required stop-band attenuation is increased by A dB to compensate for the required signal power increase caused by the filter's loss.

Figure 18—Band stop filter specification.

Note: The filter's response shall fall between the hatched areas.

Because there is less 8-VSB power within the first ½ MHz at each edge of the Channel and to allow easier filter fabrication, a slightly lower attenuation is specified at the Channel edges. To keep the amount of 8-VSB signal power required for the measurement to a value less than 1 W (+30 dBm), the filter's loss beyond 2 MHz from the Channel edge must be less than 3 dB. The resulting filter specification required to measure to the Full Service mask is shown in Figure 18.

The stop band filter required to measure to the Stringent and the Simple masks requires much less attenuation of the in-Channel 8-VSB signal. Because the band stop filter requirements are designed to reduce the analyzer's intermodulation (at the Channel edge shelves) to equal to the instrument's noise floor, the allowable 8-VSB signal power at the input mixer is the same value regardless of what mask is being measured. Since the signal power required to measure the Stringent and the Simple masks is much less than the Full Service mask, the amount of stop band filter attenuation is also much less; less by 34 dB in the case of the Stringent mask and less by 39 dB in the case of the Simple mask. Therefore, when measuring to the Stringent mask, the filter must exhibit a minimum stop band attenuation of 12 dB and only 7 dB is required when measuring to a Simple mask. Some analyzers with better specs than assumed for this document may not need any band stop filtering to measure the Simple and Stringent emission masks.

Example:

Suppose an instrument with a two-tone TOI of +25 dBm and a 10 kHz sensitivity of -105 dBm is available. Can it measure a transmitter to the Stringent mask?

$$dB_{DTV}\ Meas.\,Capbility \approx 8 - \frac{2}{3}\left(\left(TOI - 3\right) - 10kHz\ Noise, dBm\right)\mathrm{dB}_{\mathrm{DTV}} \tag{35}$$

$$dB_{DTV}\ Meas.\,Capbility \approx 8 - \frac{2}{3}\left(\left(25 - 3\right) - \left(\text{-}105\right)\right)\mathrm{dB} = \text{-}76.7\mathrm{dB}_{\mathrm{DTV}}$$

This instrument should be able to measure the -76 $\mathrm{dB}_{\mathrm{DTV}}$ ultimate attenuation required by the Stringent Mask.

6.3.2.3 Measurements With the Band Stop Filter in the Signal Path

The response after a typical band stop filter has been inserted in the signal path and with the attenuation ahead of the input mixer appropriately adjusted (lowered by more than 46 dB) to find a *new* Sweet Spot is shown in Figure 19. This drawing assumes that the signal amplitude was adjusted to bring the total 8-VSB power back to *approximately* the same input power as shown in Figure 17. This is a conservative setting because it brings the instrument's intermodulation equal to its noise floor near the Channel Edge, thus once again allowing the spectral roll-off to provide additional margin.

Since the amplitude of the intermodulation droops at frequencies away from the Channel Edge, the mixer's input amplitude should be adjusted again to find the Sweet Spot to maximize the signal's dynamic range in a manner similar to the method shown in Figure 15 but focusing on the frequency range about 3 to 5MHz from the edge of the Channel. However, there may be times where this second adjustment to find the Sweet Spot is unnecessary since all of the analyzer's input attenuation has been removed and the filtered in-band 8-VSB Emissions is not back at the original signal levels as before the filter was inserted.

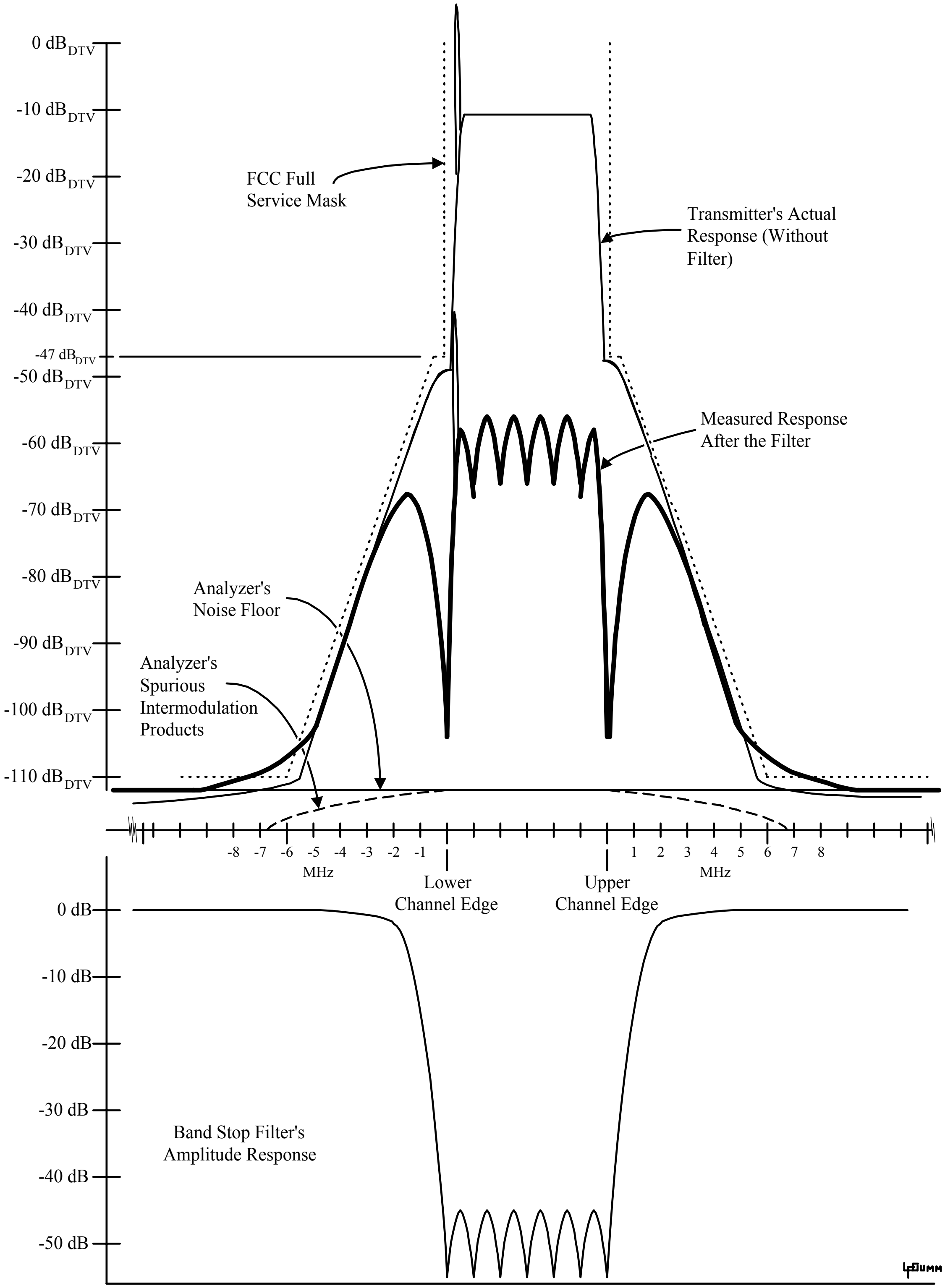


Figure 19—(upper) The measured response after insertion of a typical band stop filter (lower) has been inserted in the signal path and the input signal amplitude appropriately adjusted.

6.3.2.4 Correcting Measurements Made with the Band Stop Filter

Amplitudes measured with and without the band stop filter will be in the correct relationship with each other except for errors caused by its pass band insertion loss.

The band stop filter must be characterized to determine its losses. Since this filter features very sharp variations in loss over small frequency ranges, it is important to determine its characteristics virtually each time it is used to account for any drift. The required measurements are shown in Figure 20. The loss at the center of each 500 kHz frequency Sub-Band must be measured. ***Because this loss reduces the amplitude of the Emissions signals with respect to the measured value of the total in-band average signal power, it causes the measured Emissions to be understated by that amount.***

Adjacent Channel Stop Band Filter Response

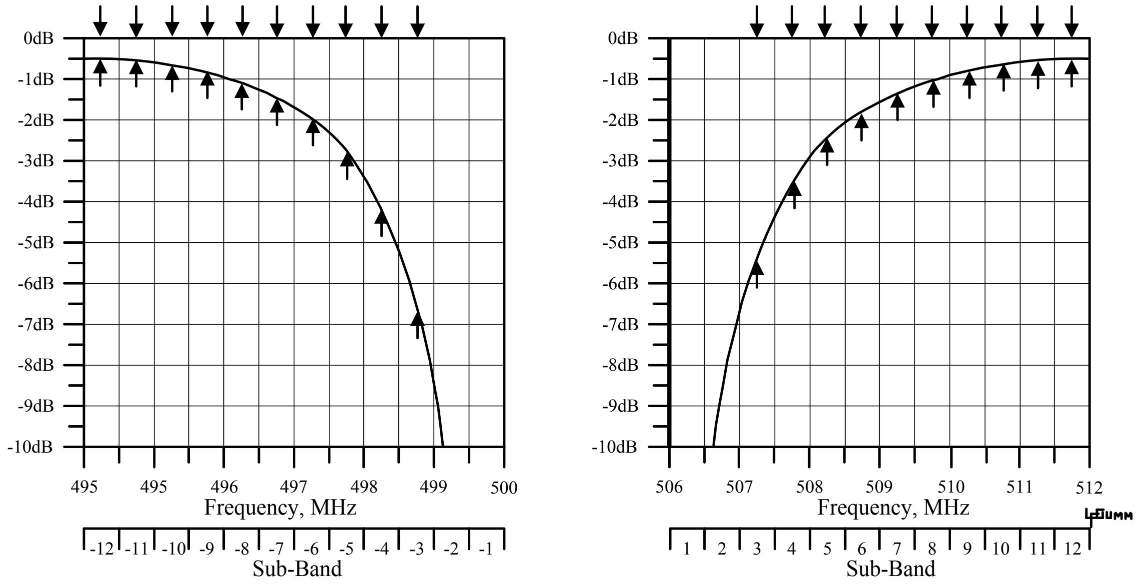


Figure 20—Required band stop filter measurements.

Note: Measure the loss at the *midpoint* of each Sub-Band that is used for Emissions measurements through the filter.

Because the data is displayed in dB, the average loss across a given Sub-Band is not quite equal to its midpoint's value, causing a small error. To limit the size of this error to less than 0.3 dB, do *not* use a band stop Sub-Band measurement if the *variation* of the filter's loss across that 500 kHz Sub-Band is greater than 6 dB. *(See Figure 23 and Table 3)*

To correct the Emissions absolute power measurement for the stop band filter's loss, ***add*** the value of the midpoint *loss* (considered a positive number) to the reading to obtain the correct value.

Example:

The loss at the midpoint of Sub-Band -4 of a stop band filter was measured to be 2.3 dB. Using band power markers, the Emissions in that 500 kHz Sub-Band were measured to be -80 dBm in amplitude. What is the corrected amplitude?

$$\text{Corrected Amplitude} = (-80\ \text{dBm}) + 2.3\ \text{dB} = -77.7 \approx -78\ \text{dBm} \qquad (36)$$

6.3.3 Compliance Measurements Using the Transmitter’s Channel Filter

6.3.3.1 General

To measure a Full Service transmitter’s Emissions using available test equipment, the amplitude of the DTV signal’s Out-of-Channel Emissions must be increased with respect to the 8-VSB signal. The method described here makes use of the transmitter’s Channel (Emissions mask) Filter installed between the power amplifier and the antenna of all Full Service transmitters to, in effect, do so.

This method is useful in that a filter already present in all Full Service and Stringent mask transmitters is used to limit out-of-band Emissions instead of requiring a separate band stop filter. While attractive for manufacturing settings, it is considered less desirable for field use because, to be accurate, it requires that accurate Channel Filter attenuation data be available.

6.3.3.2 Connections

The connections for this method are shown in Figure 21. Normal measurements of in-Channel signal power and close-in Emissions performance are made with a sample of the signal going to the antenna at point ‘Q’.

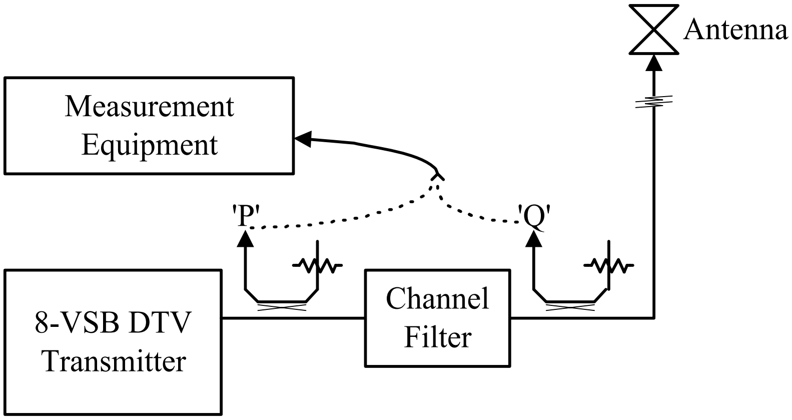


Figure 21−Using the transmitter’s Channel Filter to make -110 dB_{DTV} out-of-Channel Emissions measurements

When amplitude measurements of the transmitter’s extreme out-of-Channel Emissions are required (e.g. beyond three or four Sub-Bands into the adjacent Channel), the measurement equipment is connected to point ‘P’, *before* the Channel Filter. In this way, the out-of-Channel Emissions are easily and accurately measured at the higher amplitudes present before the filter’s attenuation. After measurement, the filter’s *attenuation* response is subtracted (in dB) from the measured values to determine the final result.[11]

This approach requires that accurate attenuation vs. frequency data for the filter under *operational* conditions (i.e., at operating temperature) is available. This may be essentially

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[11] *Attenuation* is a measure of a passive filter’s loss and is always considered to have a positive dB value. The filter’s *throughput* typically shows negative dB value meaning less power came out of the filter than went in. Attenuation is just the negative of throughput.

impossible, when a non-temperature compensated filter is used. Or, it may be just difficult, when it requires taking the transmitter off of the air and dismounting what are often large and clumsy fittings; which in turn, can perhaps cause damage leading to poor system reliability or even failure.

To reduce measurement uncertainty due to a mismatch to less than ±0.3 dB, the directivity of the coupler at ‘P’ must exceed 30 dB over a frequency range of ± 9 MHz (minimum) from the center of the transmitter’s Frequency. The return loss requirements specified in 4.5 also apply to this coupler.

The process is shown in Figure 22. The middle traces in this figure are the measured Emissions characteristics before and after the Channel Filter. The response *before* the filter shows the intermodulation Shoulders starting at -48 dB_{DTV} and decreasing slowly away from the Channel edge. The response *after* the Channel Filter falls off far more rapidly due to the filter’s steep attenuation versus frequency response, but the measurement instrument’s dynamic range limits the measurement to a bit more than -70 dB_{DTV}. In the figure, the Channel Filter’s response is superimposed on the emission characteristics using the same dB and frequency scale. The in-band loss of any suitable Full Service Channel Filter will be very low and can be assumed to be essentially zero.

6.3.3.3 Measurements

To determine the transmission system’s complete response, the Channel Filter’s response is added (in dB) to the transmitter’s response taken *before* the Channel Filter. For example, if Channel Filter’s response (i.e. throughput) is -10 dB at a particular frequency, a new point is added to the graph 10 dB *below* the Before the Channel Filter’s response (i.e., adding a negative number to the measured value). The dotted line shows the *calculated* result when this is done over the full frequency range. Plotting the dotted curve on top of the response measured after the Channel Filter allows the known part of the final response to be compared with the computed portion, thus verifying the correctness of the final result. This approach, shown graphically here, can also be performed in a tabular format if more convenient.

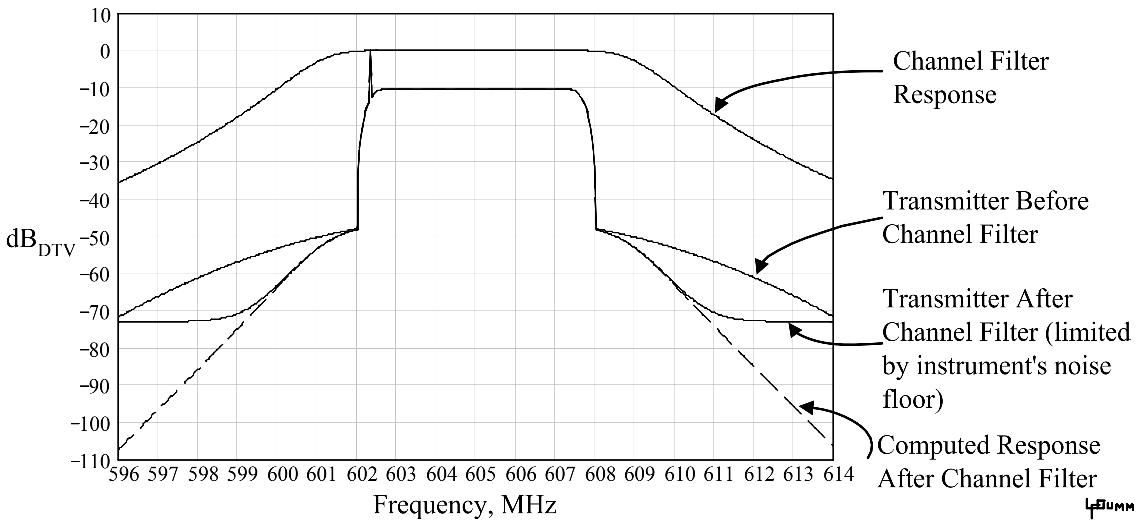


Figure 22−The Channel Filter's response combined with the Emissions measured prior to the filter to determine the transmitter's total Emissions

In principle, point-by-point frequency measurements of pre-filter Emissions and filter attenuation could be taken and the transmitter's Emissions computed using Method 1 of 4.6.5. This is a good approach when measurements are controlled by a computer but requires too many measurements when being done manually. For manual measurements, it is better to rely upon Method 2 of 4.6.5 which requires Band Power Measurements across 500 kHz Sub-Bands. However, problems arise when an attempt is made to combine the power measured across the 500 kHz Sub-Band with a single Channel Filter attenuation value (e.g., filter attenuation at the center of a 500 kHz Sub-Band). Since the response is in dB, its average loss is not the attenuation value at the Sub-Band's midpoint. However, it is possible to estimate and correct this error within a small tolerance.

6.3.3.4 Corrections

Figure 23 shows how the filter's response can be approximated by noting its mid point attenuation in dB and the slope in dB per 500 kHz Sub-Band of a line drawn parallel to the filter's transfer characteristic. The filter's *attenuation* in each Sub-Band is thus approximated by a straight line. However, because the slope is linear in dB, the mid point attenuation value of that line does not give the correct value of the *average* attenuation across the 500 kHz Sub-Band.

To compute the size of this effect, the midpoint filter attenuation, L dB in Figure 23, is assumed to be zero. The linear filter attenuation ramp is assumed to represent a power spectrum with the same characteristics. Using discrete calculations, a large number of points along the linear ramp function are individually exponentiated to give its equivalent linear power (which is no longer a ramp function). The points are then summed, and divided by the number of samples to determine the average power of all the points across the Sub-Band. This result is then re-logged to determine the average value with respect to the mid-point value.

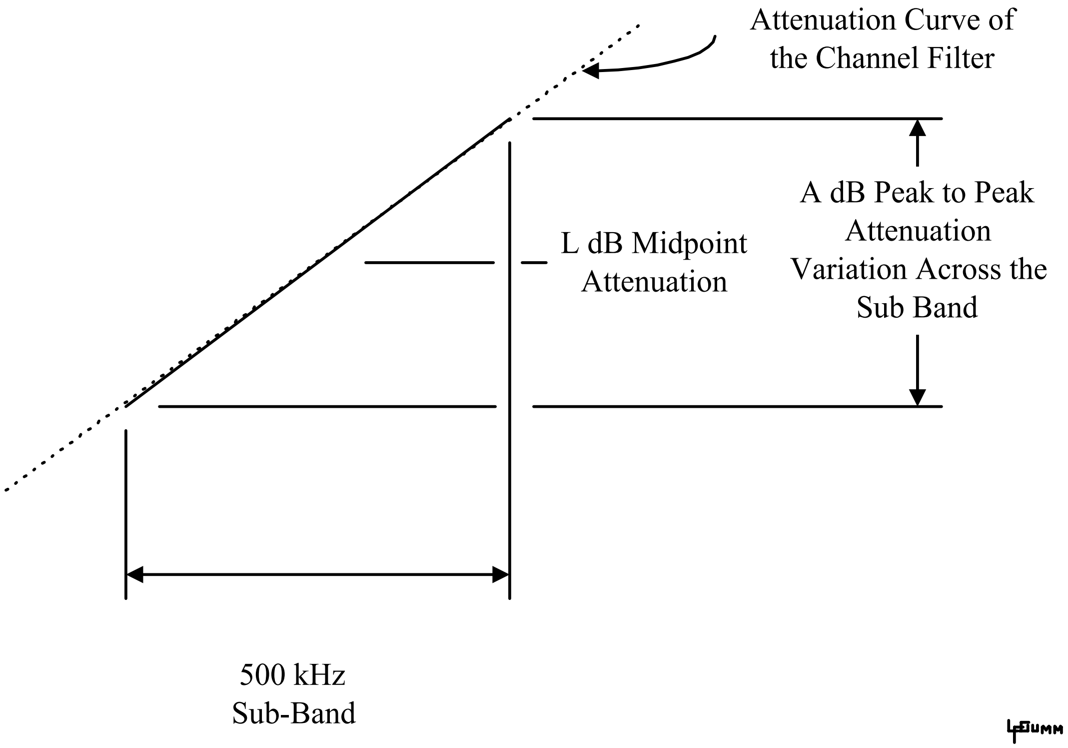


Figure 23--Filter Response Across a 500 kHz Sub-Band

For background, the mathematics used is as follows: N points will be computed with a running variable, n, that varies from 0 to N-1

The ramp, R, of the filter's logarithmic output response is then:

$$RdB(n) = AdB\frac{n}{\mathrm{N}-1} - \frac{AdB}{2} \tag{37}$$

Assuming that the filter response ramp represents a power spectrum, the linear power at each point is then:

$$P(n) = 10^{\frac{RdB(n)}{10}} \tag{38}$$

The average linear power is then:

$$\mathrm{Pavg} = \frac{1}{\mathrm{N}}\sum_{n} P(n) \tag{39}$$

The average power across the entire Sub-Band, expressed in dB is then:

$$dBoutput = 10\log(Pavg) \tag{40}$$

The calculated average power is then compared to the midpoint attenuation of the filter. Results of this computation, using N > 1000 rounded to 2 decimal places, are given in Table 3.

Filter slope across Sub-Band A dB	Correction factor to be subtracted from filter midpoint value dBout
5.75	0.31
6	0.34
7	0.46
8	0.60
9	0.75
10	0.92
11	1.11
12	1.31
13	1.52
14	1.75
15	1.99
16	2.23
17	2.50
18	2.77
19	3.05
20	3.34
21	3.62
22	3.93
23	4.29
24	4.56
25	4.89
26	5.22
27	5.56
28	5.90
29	6.25
30	6.60

Table 3—Slope Attenuation Factor or the Amount the Average Attenuation is ***Less*** Than the Mid-Point Attenuation for the Function Shown in Figure 23

For instance, if the attenuation varies by 10 dB peak-to-peak across the Sub-Band, the average **response** is 0.92 dB ***greater*** than the response at the Sub-Band’s center. That is, the filter’s average **attenuation** across that Sub-Band is 0.92 dB ***less*** than the attenuation at that Sub-Band’s center.

Because the filter’s *average* attenuation is **LESS** than the mid point attenuation, the actual Emissions are **GREATER**. Therefore, the midpoint attenuation value in this example will **UNDERSTATE** the average emission by nearly 1 dB.

Note: The “out-of-sequence value” of 5.75 dB in the table above is the value of dB change per Sub-Band of the linear slope portions of the Full Service and Stringent LPTV Emissions masks. By stating in the public notice that the midpoint of the mask’s attenuation over each Sub-Band is to be used in the Sub-Band method, the FCC, in effect, requires an additional 0.31 dB of attenuation over the value than would be needed if a point by point measurement were performed in that Sub-Band. (*See 4.6.5*)

Example:

The Emissions on the upper side of a Channel 15 transmitter are being measured to -110 dB_{DTV}. The Channel Filter’s response is shown in Figure 24. In the first MHz from the Channel edge, (i.e., Sub-Band 1 and 2), the filter is in the transition zone between its pass-band and its stop band. Emissions measurements for this frequency range are made at the filter’s output.

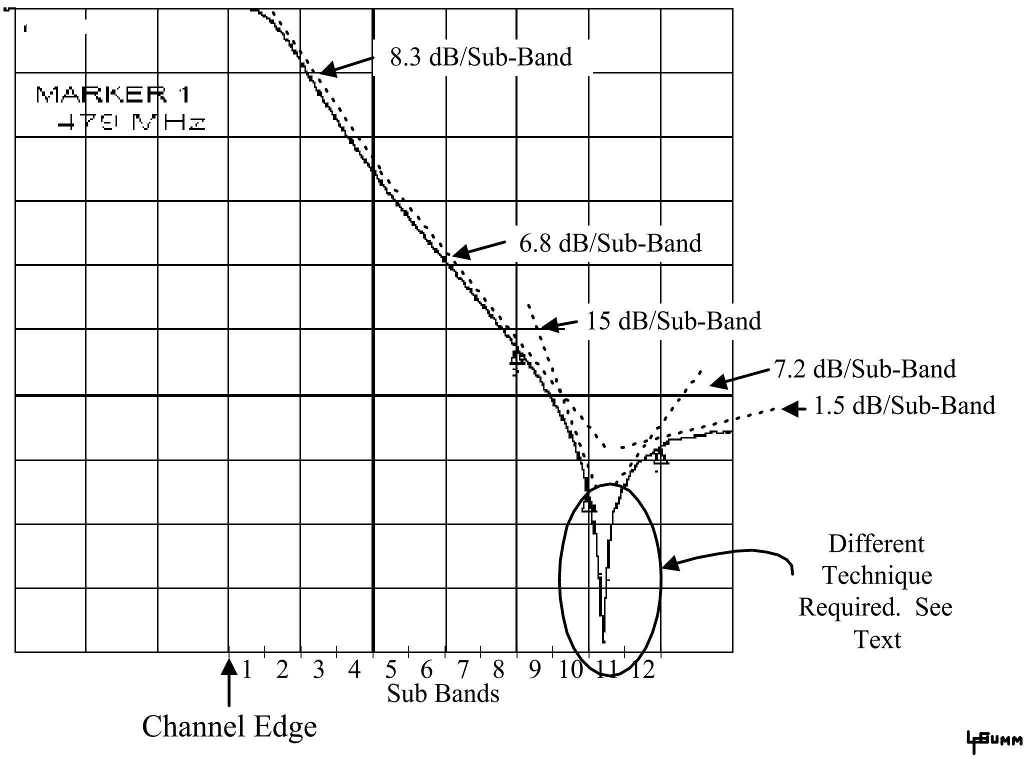


Figure 24-Determining Filter Slopes Per Sub-Band

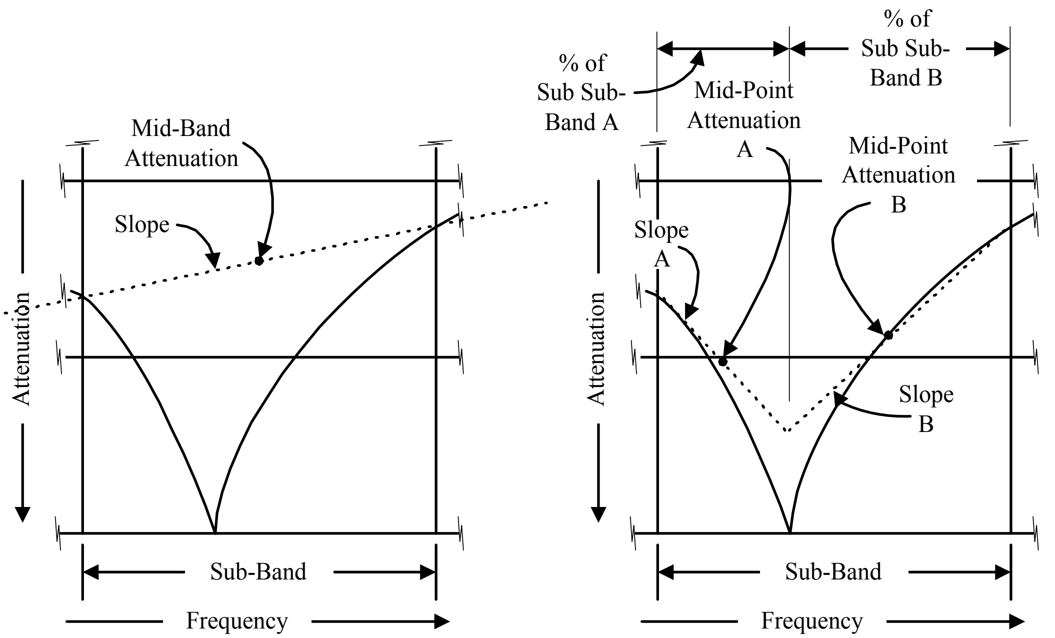
A straight line drawn along the response with a slope of 8.3 dB/Sub-Band closely fits the response in the second MHz from Channel Edge (i.e., Sub-Bands +3 and +4). The mid point attenuation of Sub-Band +3 is about 14 dB. The Slope Attenuation Factor for an 8 dB slope is 0.6 dB. Combining this correction value with the midpoint attenuation gives a total Sub-Band attenuation value of:

$$(14\text{ dB} - 0.6\text{ dB}) = 13.4\text{ dB} \approx 13\text{ dB} \qquad (41)$$

The 13 dB value is subtracted from the amplitude of the 500 kHz Sub-Band 3 Emissions measured at the Channel Filter's input to arrive at the correct Emissions amplitude at the transmitter's output. (Calculations should be performed in tenths of a dB to avoid accumulations of round off error. The final value should then be rounded to the nearest whole dB to reflect the accuracy of the input data.)

With the exception of the circled region near the attenuation peak (i.e., filter response zero or null), the average attenuation for the other Sub-Bands is determined the same way using the straight line approximations shown. Note that it does not matter which way the line is sloped as long as it fits the attenuation curve adequately.

Channel Filters typically have an attenuation peak (sometimes called a "null" or a "zero") in the response in the first 6 MHz from the Channel edge. Sometimes, with only a modest amount of "fitting" straight line segments similar to above can be fitted to the curve. Often, however, as in the case shown in Figure 24, the zero is sharp, narrow and offset from the Sub-Band boundary. When this is the case, two different solutions may be employed.



(Approximation 1) (Approximation 2)

Figure 25—Dealing with an Attenuation Peak (See Text)

The premise of the first is based upon the fact that all that the measurements are required by the FCC to show is that the transmitter's Emissions are ***below*** the limits given by the mask. As long as the Emissions are below the mask, it does not matter by how much.

Because the attenuation peak is a narrow feature on the filter's attenuation curve, and the transmitter's pre-filter Emissions are broad slowly changing values, the filter's attenuation on either side of the zero will normally be sufficient to meet the Emissions mask. Therefore, in any but the most extraordinary situations, the method used in Approximation 1 in Figure 25 may be used. Here, the attenuation peak is ignored and a line connecting the attenuation curve at each *edge* of the Sub-Band is drawn. The slope of that line and its mid-point attenuation are used to calculate the Sub-Band's Emissions using the method given above. The Emissions thus calculated are an ***upper bound*** for the transmitter's Emissions in this Sub-Band and will be larger than the its actual Emissions. But, so long as this upper bound of Emissions amplitude is smaller than the mask, the transmitter is in compliance with the FCC regulations.

If there is insufficient margin, the attenuation of the peak must be more closely modeled as shown as Approximation 2 in Figure 25. Here, the attenuation in the Sub-Band is sub divided into two (or more) segments, each modeled as a straight line. The slope and mid-point attenuation of each straight line segment is used with the method above to calculate its average attenuation. (The Slope Attenuation Factor calculation is correct for all straight line segments linear in dB, regardless of width.) Once determined, the corrected average attenuation values for each straight line segment are combined by exponentiating each value to determine its equivalent attenuation power ratio, weighting (multiplying) that value by the proportion it occupies within the Sub-Band, adding all the weighted power attenuation values together, then finishing by converting the combined power attenuation value back into dB. This is best illustrated with an example:

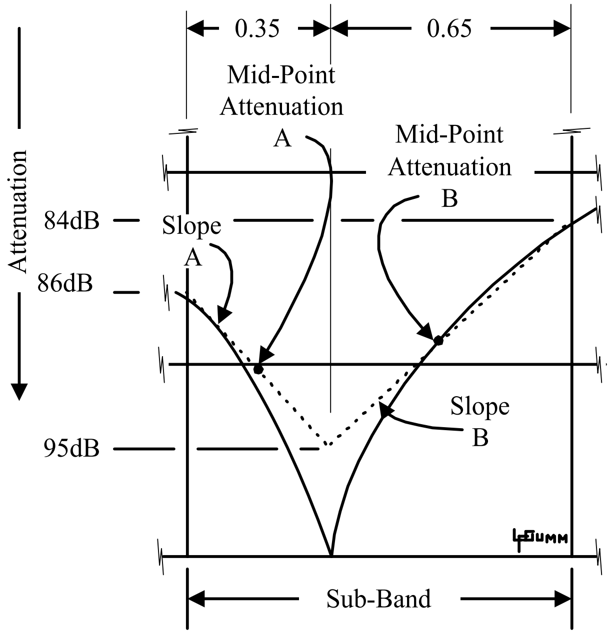


Figure 26—Example of Subdividing a Sub-Band Containing an Attenuation Peak

Example:

An enlarged version of Sub-Band 11 from Figure 24 is shown in Figure 26. The attenuation peak is modeled with two line segments. The first segment extends 35% of the way across the Sub-Band beginning at 86 dB and extending to 95 dB of attenuation. The second segment extends 65% of the way across the Sub-Band, beginning at 95 dB and ending at 84 dB. (The line segments are deliberately kept above the attenuation curve so that the approximated value will understate the actual attenuation.)

The first segment's midpoint attenuation is then:

$$\text{Midpoint Attenuation}(1) = \frac{86\text{dB} + 95\text{dB}}{2} = 90.5\text{dB} \tag{42}$$

The first segment's slope is:

$$Slope(1) = 95\text{dB} - 86\text{dB} = 9\text{dB} \tag{43}$$

The Slope Attenuation Factor for a 9 dB slope across the sub Sub-Band from Table 3 is:

$$\textit{Slope Attenuation Factor(1)} = 0.75\text{ dB}$$

The first segment's average attenuation is then:

$$\textit{Average Attenuation(1)} = \textit{Mid-Point Attenuation(1)} - \textit{Slope Attenuation Factor(1)} \tag{44}$$

$$\textit{Average Attenuation(1)} = 90.5\text{ dB} - 0.75\text{ dB} = 89.75\text{ dB}$$

Similarly, is found that the average attenuation of the second line segment is

$$\textit{Average Attenuation(2)} = 88.39\text{ dB}$$

The two values are combined in proportion to the amount of the Sub-Band they occupy:

$$\textit{Total Attenuation} = 10\log\left(L(1)10^{\frac{\textit{Average Attenuation}(1)}{10}} + L(2)10^{\frac{\textit{Average Attenuation}(2)}{10}} \right) \tag{45}$$

where: L is the proportion of the Sub-Band each sub sub-segment covers.

Entering the example's values:

$$Total\ Attenuation = 10\log\left((0.35)10^{\frac{89.75}{10}} + (0.65)10^{\frac{88.39}{10}} \right) = 88.91\text{dB} \approx 89\text{dB}$$

This process can be extended to as many line segments as needed by calculating the average attenuation of each line segment as above and combining them using the following equation.

$$Total\ Attenuation = 10\log\left(L(1)10^{\frac{Average\ Attenuation(1)}{10}} + L(2)10^{\frac{Average\ Attenuation(2)}{10}} + \ldots + L(n)10^{\frac{Average\ Attenuation(n)}{10}} \right) \quad (46)$$

Note:

A further point about the correction process should be made. The process of determining the average signal amplitude per Sub-Band and then subtracting the average attenuation per Sub-Band, *assumes* that the transmitter's spectrum changes slowly over any given 500 kHz Sub-Band. If it does not, the method yields an *understatement* of the transmitter's output.

Experience shows that the transmitter's output spectrum (as fed to the Channel Filter) has a small variation over each Sub-Band; typically in the range of 1 to 2.5 dB. Experience also shows that the attenuation slope per Sub-Band of a typical Channel Filter is somewhat less than 10 dB (away from any attenuation peaks). To illustrate the magnitude of error from typical worst case conditions, assume the transmitter's spectrum has a slope of 3 dB while that of the Channel Filter is 10 dB across a given Sub-Band.

The actual slope at the filter's output is 13 dB per Sub-Band. If directly measured, the result is a value 1.52 dB greater than the midpoint amplitude of that Sub-Band. When the transmitter's 3 dB per Sub-Band slope is measured at the filter's input, the result will be 0.09 dB greater than the Sub-Band's amplitude.

The correction for the 10 dB per Sub-Band filter slope is 0.92 dB. Using the indirect measurement method above the Emissions would be measured as 0.09 dB + 0.92 dB equals 1.01 dB instead of the 1.52 dB than the mid Sub-Band amplitude obtained by direct measurement. Thus the measurement error when using the indirect method under extreme conditions is only 0.5 dB.

This error could be mostly removed by adding yet another layer of approximate corrections to the procedure. However, given its small size, the already sizable measurement uncertainty and the probability of the added complexity causing errors, this error was acknowledged and allowed to remain.

Annex A

(Informative)

Measurement of Spectrum Analyzer 8-VSB HSI vs. TOI (or IP3) Relationship

With equipment and facilities provided by Agilent, Rohde and Schwartz and Tektronix, measurements were made to determine the relationship of the (two-tone) Third Order Intercept amplitude (TOI or IP3) exhibited by a spectrum analyzer to its 8-VSB Head-to-Shoulder intercept amplitude (8-VSB HSI).

TOI is a measure of intermodulation performance. For spectrum analyzers, it is determined by applying two CW signals of *equal* amplitude with a small frequency separation to the analyzer's input and observing the amplitude of the $2F_1$-F_2 and $2F_2$-F_1 spurious responses that fall near by as the signal's amplitudes are varied. When the amplitude of the signals is sufficient to cause the spurious responses to appear, these spurs will increase 3 dB in amplitude for every dB the signals are both increased; that is, the amplitude *difference* between the signals and the spurs decreases 2 dB for every dB of increase in the signal's amplitude. *(See Figure 13)* The spectrum analyzer's TOI is that input amplitude that, by extrapolation, would cause the CW signals and their spurs to be equal in amplitude. The input amplitude is typically referred to the analyzer's *mixer* input (i.e., after its internal attenuator). TOI amplitudes are always determined by extrapolation because the 2X slope relationship is only true at input amplitudes well away from instrument overload (i.e., compression) [B6].

The 8-VSB signal used for DTV transmission in the United States has a spectral shape that is flat across most of the Channel with narrow root-raised-cosine transitions at each Channel Edge [B2]. It exhibits the effects of any third order intermodulation by the appearance of "Shoulders" or spectrum regeneration at its Channel Edges. *(See Figure 1)* [B7] The amplitude difference between the Head or flat portion of the 8-VSB spectrum and these Shoulders also varies at a 2:1 rate with respect the 8-VSB signal's amplitude. It is convenient, then, to ***define*** **8-VSB HSI (Head-to-Shoulder intercept) as the (extrapolated) amplitude of the total 8-VSB signal power required to cause the Shoulders of the 8-VSB signal to be equal in amplitude to the Head or flat portion of the 8-VSB spectrum**.

To determine the relationship between TOI and 8-VSB HSI in spectrum analyzer equipment, careful measurements were made of several modern instruments. The first step was to determine each analyzer's actual TOI. This was performed at 580 MHz with two sine wave generators coupled together through a hybrid coupler to combine the signals while providing good generator-to-generator isolation. The signals were separated by 3 MHz in frequency. The combined signals were then passed through transmission line traps to reduce any second or third harmonic signals present. The combined signals were varied in amplitude using a 1-dB step attenuator and then applied to the input of the spectrum analyzer.

The instruments were adjusted to force a zero RF attenuation value and then set to the largest reference level achievable under that condition (typically about 0 dBm). Measurements at each amplitude were made using the analyzer's marker system to determine the amplitude of each signal and the amplitude differences between the signals and their spurious responses. By doubling the signal-spur amplitude difference and adding this value to the signal's amplitude, an extrapolated TOI value was calculated. (Since there were slight variations of the signal-spur amplitude between the spurs, an average spur value was used.) Extrapolated data points calculated from data taken at several input amplitudes was used to compute an average TOI amplitude for a given spectrum analyzer. Confidence in the results was increased by the fact that the measured TOI values agreed closely with each analyzer's published *typical* TOI specification.

Then, using an 8-VSB source, measurements were made to determine the analyzer's 8-VSB HSI. While the source was excellent, it was not free of its own Shoulder Emissions. The amplitude of its Shoulders were determined by using one of the analyzers that exhibited a high TOI to measure the 8-VSB source over a range of amplitudes well below those that would cause that analyzer to produce any third-order distortion (i.e. Shoulders) of its own. The power of the generator's Shoulder was then subtracted from the power of the measured Shoulder amplitudes as the analyzers were measured.

The 8-VSB source was adjusted to a frequency 580 MHz (i.e., its signal extended from 577 MHz to 583 MHz). No harmonic filter was required because the 8-VSB source exhibited a low harmonic content. Each analyzer was measured in a 10 kHz resolution bandwidth using a sampling mode detector and heavily averaged to achieve a stable reading. The instrument's default video bandwidth was used.

The instruments were adjusted to force a zero RF attenuation value and then set to the largest reference level achievable under that condition (typically about 0 dBm). The 8-VSB signal was applied to the instrument through a 1 dB step attenuator, starting at a low amplitude and increasing in small steps. At each input amplitude, the instrument's Band Power Measurement mode was used to determine the total applied 8-VSB signal power across the 6 MHz Channel while delta markers were used to determine the amplitude difference between the Head or flat portion of the 8-VSB spectrum at mid Channel and the amplitude of the Shoulder at a frequency 50 kHz above the upper Channel Edge. (Experience indicates that the amplitude of the Shoulder on the upper Channel Edge is normally equal to or greater than the Shoulder at the lower edge.)

The measured Head-Shoulder difference values were corrected to subtract the power of the 8-VSB source's own Shoulder. Then, the corrected Head-to-Shoulder amplitude difference was doubled and added to the measured total 8-VSB power to extrapolate to an 8-VSB HSI value. Because the instruments had been constructed to be resistant to showing the effects of intermodulation, rather large input signal amplitudes had to be used to bring the Shoulder created in the instrument far enough above the source's Shoulder to allow reasonably accurate measurement. (The total 8-VSB signal applied to the instruments was kept below 0 dBm to avoid damaging the instruments.) This meant that the extrapolated 8-VSB HSI as a function of input amplitude increased from a low value to a peak and then fell as the total power of the signal was increased into the range where the distortion was not "well behaved" (i.e. the slope of the Head-to-Shoulder amplitude difference with input amplitude changes became much larger then 2X). The 8-VSB HSI was taken to be the 8-VSB HSI exhibited at the peak.

The results from the analyzers were similar. **The maximum 8-VSB HSI exhibited was from 2 to 4 dB (or about 3 dB) *less* than its measured TOI** (that is, if the analyzer exhibited a +18 dBm TOI, the 8-VSB HSI was about +15 dBm. Knowing this value allows an analyzer's 8-VSB performance to be predicted on the basis of its published or measured TOI specification.

Annex B

(Informative)

Effects of 8-VSB Pilot Offsets on Meeting FCC Emissions Mask Requirements

Introduction:

Only Full Service Transmitters are required by the FCC to offset their Pilot Frequency. As noted in 4.2, when the pilot carrier is offset in frequency from its normal value, it makes it more difficult for an 8-VSB transmitter to meets its Emissions mask. This annex includes description of the various offsets and calculates the expected change of Sub-Band 1 Emissions caused by those offsets based on a simple model. The model is also used to calculate the improvement in the transmitter's Emissions performance required for a transmitter that just meets the mask before offset to meet the mask after offset.

There are roughly 210 Full Service DTV assignments in the USA that require operating with an offset pilot carrier frequency. Of these about 1/3, or perhaps 70, are offset by the maximum nominal 32.7 kHz. Because of the more difficult problems caused by this large offset (noted below), these 70 stations may require special effort to meet the FCC's mask requirement until the analog system is shut down thus removing the FCC's mandated Pilot Frequency offset.

This Annex examines the extra difficulty that will be encountered by an 8-VSB DTV station in meeting the Full Service emission mask when the pilot is offset by a positive 9.7 kHz, 12.7 kHz, 19.4 kHz, 22.7 kHz and 32.7 kHz.

Sources of 8-VSB Pilot Offsets:

From the FCC

The FCC requires certain 8-VSB stations that are sited close to lower adjacent Channel analog TV stations to offset their pilot carrier frequency. This is intended to minimize interference caused to the analog signal. When offset is required, the pilot signal is must be 5.082,138 MHz (± 3Hz) above the analog station's picture carrier frequency so the 8-VSB Pilot's Frequency is, in effect, set by the analog station [FCC 47CFR§73.622(g)]. The FCC requires that the nominal picture carrier frequency of many analog TV stations be offset by ± 10 kHz from the nominal carrier frequency [FCC 47CFR§73.606(a)),]. Combining all the effects, when offset, the DTV station's Pilot Frequency will be nominally be 12.7 kHz, 22.7 kHz or 32.7 kHz higher than its normal value depending on whether the analog station is offset -10 kHz, 0 kHz or +10 kHz respectively. These offsets are only required because of the presence of analog TV stations. Presumably the need for most offsets will disappear when the analog TV broadcasts are discontinued. This will free offset DTV stations to return to non-offset operation. However, offset operation may be required for lower adjacent channel DTV stations after Full Service analog stations are turned off.[FCC 47CFR§73.622(g)]

From the ATSC A/64

The Advanced Television Systems Committee's, A/64 Standard: "Transmission Measurements and Compliance for Digital Television", describes an offset between DTV to DTV co-Channel stations to minimize interference [B8]. At this writing, the FCC's regulations do not mention this offset but it could be used in the future, so its effect was calculated and included in this Document. If used, the Pilot Frequencies of the two DTV stations maintain a difference in their Pilot Frequencies of 19.4 kHz. It is unclear how this would be carried out. For instance, one pilot could be offset either plus or minus the entire

19.4 kHz, or perhaps each pilot carrier could be offset one-half the difference or about 9.7 kHz but each in opposite directions. Because the shape of the 8-VSB response is symmetric near the Channel Edges, its effect on out of Channel emissions is the same, regardless if the offset is positive or negative.

Offset Effects of Ideal Transmitters

The emission from an ideal 8-VSB transmitter, by design, virtually fills the entire 6 MHz frequency range of the TV Channel; filled, that is, with the power of the noise-like Emissions when calculated in a one Hertz bandwidth. Any offset, then, will cause some portion of these narrow bandwidth Emissions to move outside the Channel. But, measurements are always made in a wider bandwidth which causes the apparent width of the transmitter's spectrum to appear wider. Figure 27 illustrates this effect. It shows the **calculated** response near the upper Channel edge of both non-offset and offset ideal 8-VSB transmitters, **all as measured in a 10 kHz Resolution Bandwidth** similar to a spectrum analyzer. In that bandwidth, the response of the non-offset ideal transmitter measures only -51 dB_{DTV} at the Channel's edge.[12]

As the various offsets are applied to the pilot, the spectrum at the upper Channel's edge also moves higher. In doing so, the signal amplitude at the Channel's edge moves higher with each succeeding offset until the Channel edge response is only -32 dB_{DTV} with a 32.7 kHz pilot offset.

Note that even with a 9.7 kHz offset an ideal transmitter cannot meet the any of FCC's Channel Edge mask requirements if the measurement is made point by point as in Method 1 in 4.6.5. ***It is necessary then to make any practical measurements of offset transmitters using Method 2 where the average response over each 500 kHz Sub-Band is measured against the FCC's mask.***

---

[12] A -51 dB_{DTV} value for Emissions at the Channel edge of an ideal transmitter means that if actual Emissions mask measurements are made on a point-by-point basis (i.e., using Method 1 in 4.6.5) the transmitter's emissions caused by intermodulation must be at least -49 dB_{DTV} at that frequency. See 6.2.8.1 for calculation method.

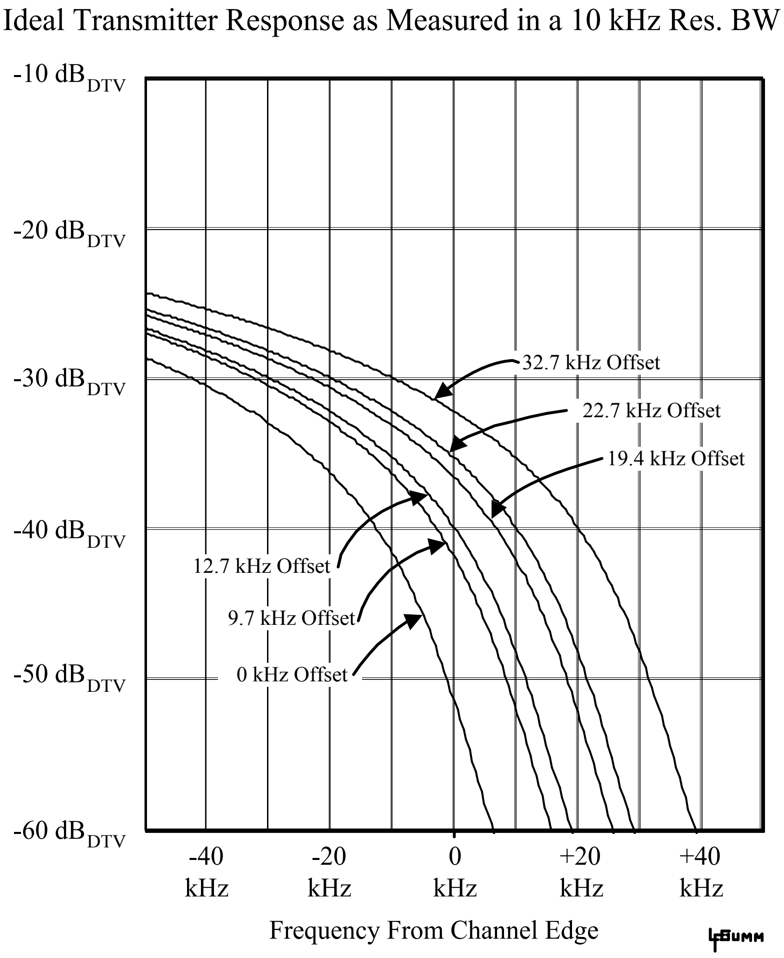


Figure 27—The ideal transmitter's Channel Edge Emissions as measured in a 10 kHz Resolution BW as a function of pilot offset frequency.

Modeling the Transmitter's Shoulder Emissions

The changes to the transmitter's Emissions caused by pilot offset are all confined to the first 500 kHz Sub-Band at the (typically upper) edge of the transmitter's Channel. Therefore, all of the modeling and calculation used in this Annex is confined to the first (+1) Sub-Band. (If the offset is negative, the same spectral shapes and effects will occur in the -1 Sub-Band.)

Simulation, while it allows a rapid and inexpensive way to determine the probable outcomes of physical experiments, is as good as the mathematical models it uses to describe the real world. To accurately simulate the effects of offsetting the 8-VSB transmitter's pilot frequency, one must create a relatively accurate yet simple enough to calculate model of its emissions at the Channel's edge.

All transmitters, to some degree, exhibit an intermodulation Shoulder at the Channel's edge. The exact spectral shape of its Emissions in the first Sub-Band depends on the details of the power amplifier's and Channel Filter's design. To minimize the complexity of the modeling process while exploring a reasonable range of options, three simple models of Shoulder Emissions were created. These are shown in Figure 28. Each model is characterized by a Channel-Edge intercept and a slope. In detail the Channel-Edge intercept amplitude (henceforth, intercept value) is the transmitter's Shoulder intermodulation amplitude at the Channel's edge ***when its Pilot Frequency is not offset***. Starting from the intercept amplitude, the transmitter's intermodulation Emissions in the first Sub-Band are then modeled with one of three straight line slopes; 0 dB/500 kHz, 5 dB/500 kHz and 10 dB/500 kHz across the first Sub-Band. Each plotted curve in Figure 28 is then the ideal transmitter's response plus the response caused by the shoulder emissions. As the pilot carrier is offset higher in frequency, the entire curve is slid higher in frequency as it would be the case with an actual transmitter.

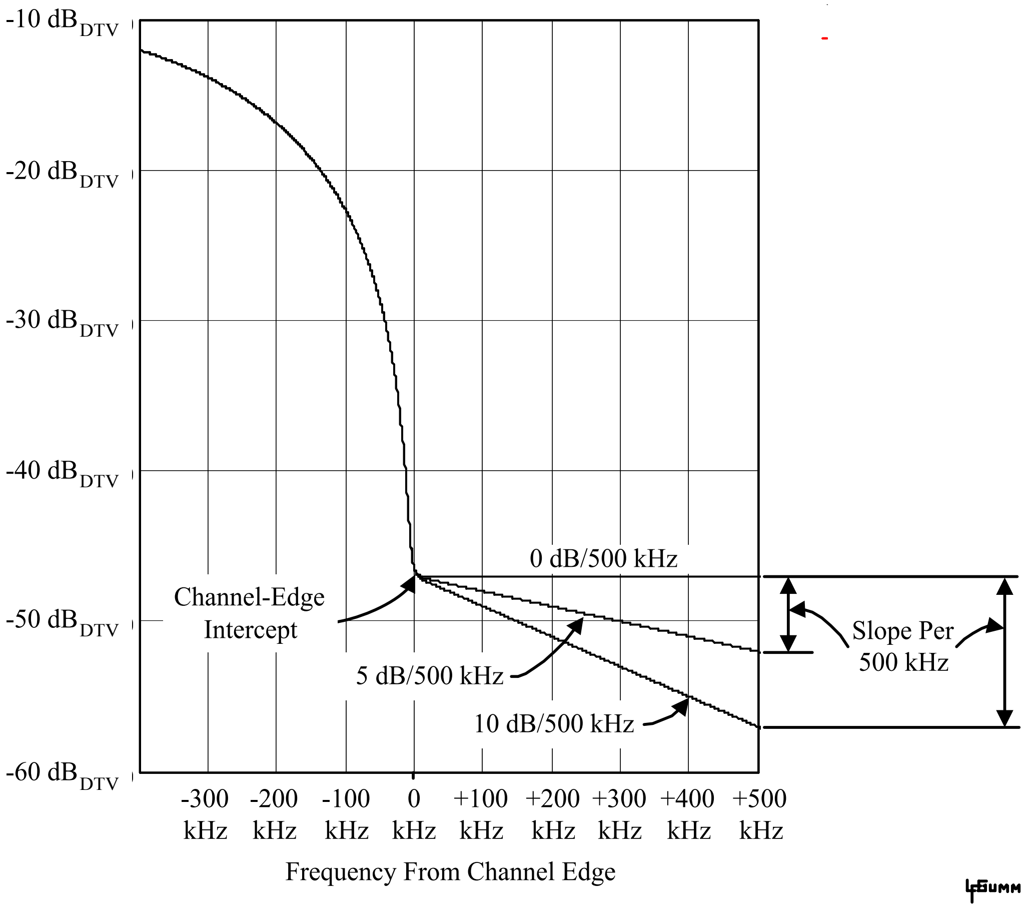


Figure 28—Shoulder Emission Models

In the modeling process, the Emissions as measured in a 10 kHz Resolution Bandwidth and scaled to a 500 kHz equivalent bandwidth for display in dB$_{DTV}$ are calculated. Then the power in the Sub-Band is calculated by summing the Emission's power starting at 5 kHz from the Channel Edge and extending across the rest of the Sub-Band and similarly scaling the result to a 500 kHz bandwidth for a result in dB$_{DTV}$. (*See 4.4 and 4.6.5*)

The model's various slopes produce some odd effects. When the Emissions across the Sub-Band have a zero slope (i.e. are flat), the intercept to achieve a -47 dB$_{DTV}$ Sub-Band average power is very close to -47 dB_{DTV}.[13] If, however, the Emissions are sloped, the intercept value that produces a -47 dB_{DTV} average Sub-Band emission amplitude will be several dB above -47 dB_{DTV}. For example, note in Table 6 that when the emissions slope 10 dB across the first Sub-Band that an intercept value of -42.86 dB_{DTV} is required for the total power in the Sub-Band, to be -47 dB_{DTV}.

Simulating the Effects of Pilot Offset

The simulation starts by inserting one of the three Shoulder Emissions models into the mathematical model. Then starting with a zero pilot offset adjustment, the intercept value is adjusted until the first Sub-Band power is just -47 dB_{DTV}.

Using that intercept value, the pilot offset is then inserted into the model and the amount of power within the first Sub-Band is recalculated. The difference between the new value and -47 dB_{DTV} is the increase in first Sub-Band power that would be caused by offsetting the transmitter's Pilot Frequency if its Emissions performance is not improved.

Pilot Offset	Channel Intercept Amplitude for Zero Pilot Offset and -47 dB_{DTV} Emissions	Calculated First Sub-Band Emissions After Pilot Offset	Delta Power Into First Sub- Band Caused by Pilot Offset	Intercept Amplitude for -47dB_{DTV} First Sub-Band Emissions	Required Shoulder Emissions Performance Improvement
0 kHz	-47.001 dB_{DTV}	---	---	---	---
9.7 kHz	“”	-46.98 dB_{DTV}	0.02 dB	-47.02 dB_{DTV}	0.02 dB
12.7 kHz	“”	-46.95 dB_{DTV}	0.05 dB	-47.05 dB_{DTV}	0.05 dB
19.4 kHz	“”	-46.75 dB_{DTV}	0.25 dB	-47.27 dB_{DTV}	0.27 dB
22.7 kHz	“”	-46.56 dB_{DTV}	0.44 dB	-47.51 dB_{DTV}	0.51 dB
32.7 kHz	“”	-45.53 dB_{DTV}	1.47 dB	-49.38 dB_{DTV}	2.38 dB

Table 4—Emissions changes caused by Pilot Frequency offset computed using the 0 dB/500 kHz slope model.

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[13] The reason for the small offset from -47 dB_{DTV} is that at the Channel's edge summing the ideal signal and the intermodulation model together creates a small “bump” in the emissions. The intercept must be offset slightly lower to bring the Emissions summed across the Sub-Band down to -47 dB_{DTV}.

Pilot Offset	Channel Intercept Amplitude for Zero Pilot Offset and -47 dB_{DTV} Emissions	Calculated First Sub-Band Emissions After Pilot Offset	Delta Power Into First Sub- Band Caused by Pilot Offset	Intercept Amplitude for -47dB_{DTV} First Sub-Band Emissions	Required Shoulder Emissions Performance Improvement
0 kHz	-44.709	---	---	---	---
9.7 kHz	“”	-46.89 dB_{DTV}	0.11 dB	-44.82 dB_{DTV}	0.11 dB
12.7 kHz	“”	-46.84 dB_{DTV}	0.16 dB	-44.87 dB_{DTV}	0.16 dB
19.4 kHz	“”	-46.61 dB_{DTV}	0.39 dB	-45.12 dB_{DTV}	0.41 dB
22.7 kHz	“”	-46.42 dB_{DTV}	0.58 dB	-45.37 dB_{DTV}	0.66 dB
32.7 kHz	“”	-45.39 dB_{DTV}	1.61 dB	-47.28 dB_{DTV}	2.57 dB

Table 5-- Emissions changes caused by Pilot Frequency offset computed using the 5 dB/500 kHz slope model.

Pilot Offset	Channel Intercept Amplitude for Zero Pilot Offset and -47 dB_{DTV} Emissions	Calculated First Sub-Band Emissions After Pilot Offset	Delta Power Into First Sub- Band Caused by Pilot Offset	Intercept Amplitude for -47dB_{DTV} First Sub-Band Emissions	Required Shoulder Emissions Performance Improvement
0 kHz	-42.856 dB_{DTV}	---	---	---	---
9.7 kHz	“	-46.80 dB_{DTV}	0.20 dB	-43.06 dB_{DTV}	0.20 dB
12.7 kHz	“	-46.73 dB_{DTV}	0.37 dB	-43.14 dB_{DTV}	0.28 dB
19.4 kH	“	-46.48 dB_{DTV}	0.52 dB	-43.41 dB_{DTV}	0.55 dB
22.7 kHz	“	-46.28 dB_{DTV}	0.72 dB	-43.67 dB_{DTV}	0.81 dB
32.7 kHz	“	-45.26 dB_{DTV}	1.74dB	-45.60 dB_{DTV}	2.74 dB

Table 6-- Emissions changes caused by Pilot Frequency offset computed using the 10 dB/500 kHz slope model

Then, to simulate to what degree the offset transmitter's Shoulder Emissions must be improved to meet the FCC's mask, the intercept value that brings the first Sub-Band Emissions back to -47 dB_{DTV} is found by decreasing the intercept value until that value of Sub-Band Emissions is obtained. The difference in the new intercept value and the initial value is the amount that a transmitter that just met the mask requirement before offset must be improved to just meet the mask requirement after offset. Note that **because the offset moves some of the transmitter's in-Channel signal beyond the Channel's edge, the transmitter's Shoulder Emissions must be improved (i.e., lowered) by more than the amount of the increase of out of Channel emission noted in the first step.** Note that since the extra emissions occur near the Channel's Edge, trying to eliminate the extra emissions by adding or modifying the Channel filter will probably sharply degrade the quality of the transmitted signal.

In the preparation of this Annex, more complicated shoulder emissions models featuring a flat portion near the Channel edge followed by a second or third order roll off toward the Sub-Band's outer edge were tried, but produced results very similar to those of simple models. The very similarity of the simple models with the complex and the simple models with each other is taken to show that the problems caused by offsetting the pilot frequency is adequately illustrated with the models used.

Keep in mind that if the pilot is negatively offset that the excess emissions and improved performance will be required in the first Sub-Band on the lower side of the channel (i.e., Sub-Band -1).

Conclusions

As the three tables show, the amount of power injected into the first Sub-Band when the pilot carrier is offset depends mostly on the amount of the offset. The slope of the model has some effect but to a much smaller degree. The amount of excess Emissions injected into the first Sub-Band caused by an offset are relatively small except when the offset is 32.7 kHz. Beyond that, the transmitter that has the greatest emissions slope across the Sub-Band will inject slightly more of emissions into that Sub-Band when it is offset.

Likewise, the degree to which the transmitter's Shoulder Emissions performance must be improved is relatively small until the 32.7 kHz offset is considered. And likewise, the amount of improvement required is slightly greater with a high emissions slope. But remember that the offset causes the transmitter's normally in-Channel signal to be injected into the first Sub-Band. This causes an increase in the Emissions "floor" in that Sub-Band, resulting in a situation where the amount the Shoulder Emissions must decrease to compensate for the floor's presence **is noticeably larger than the amount of excess Emissions caused by the offset**.

Because of the effects of the typical Channel Filter on most power amplifier's broad Emissions Shoulder, most transmitters are closest to the mask's limits in the first Sub-Band at the Channel's edge (i.e., ±1). The FCC's required offsets all move the pilot carrier *higher* in frequency thus causing the Emissions in the Sub-Band at the upper edge of the Channel (i.e., +1) to be stressed. An often observed but unexplained fact is that most 8-VSB sources exhibit greater Emissions at the upper Channel Edge Shoulder than at than at the lower. Therefore, offsetting the pilot increases the Emissions stress in the very Sub-Band that normally has the least margin in normal operation.

Annex C

(Informative)

Glossary

For the purposes of this document, the following terms and definitions apply. These and other terms within IEEE standards are found in *The Authoritative Dictionary of IEEE Standards and Terms*

band-stop filter: A band-stop filter or band reject filter attenuate a desired range of frequencies and passes frequencies that are higher and lower than the rejection band. *(See 6.3.2.2)*

decibel, (dB): (A) Ten times the logarithm to base 10 of a ratio of two powers. (B) A standard unit for expressing the ratio between two parameters using logarithms to the base 10. Decibels provide a convenient format to express voltages or powers that range several orders of magnitude for a given system. (C) One-tenth of a bel, the number of decibels denoting the ratio of two amounts of power being ten times the common logarithm of this ratio. *Note:* The abbreviation dB is commonly used for the term decibel. With P_1 and P_2 designating two amounts of power,

$$n = 10 \log (P_1/P_2) \text{ dB}$$

When the conditions are such that ratios of currents or ratios of voltages (or analogous quantities in other disciplines) are the square roots of the corresponding power ratios, the number of dB or decibels by which the corresponding powers differ is expressed by the following equations:

$$n = 20 \log (I_1/I_2) \text{ dB} \tag{47}$$

$$n = 20 \log (V_1/V_2) \text{ dB} \tag{48}$$

where I_1/I_2 = The given current ratio, V_1/V_2 = The given voltage ratio. By extension, these relations between numbers of decibels and ratios of currents or voltages are sometimes applied there these ratios are not the square roots of the corresponding powers ratios; to avoid confusion, such usage should be accompanied by a specific statement of the application in question. (D) A unit of measurement for the relative strength of a signal parameter such as power or voltage. (E) The standard unit for expressing transmission gain or loss and relative power levels. Decibels indicate the ratio of power input to power output: dB = 10 log (P_1/P_2). *Note:* One decibel is 0.1 bel.

$\text{dB}_{\text{subscript}}$: dB is *always* a ratio of two values, whether voltage, current, or power. If dB is followed by a subscript, then the value is dB with respect to a *specific* value, as defined by the subscript. Examples are dBc or dBm.

dBc: dB with respect to the total average *carrier* power of a RF signal. In this document, dBc is taken to be the number of dB between a spectral feature or signal and the total average power of the 8-VSB signal within the 6 MHz Channel, including the pilot signal.

dBm: A unit for expression of power level in decibels with reference to a power of one milliwatt.

intermodulation distortion: nonlinear distortion of a system or transducer, characterized by the appearance in the output of frequencies equal to the sums and differences if integral multiples of the two or more component frequencies present in the input wave. Harmonic components also present in the output are usually not included as part of the intermodulation distortion. When harmonics are included, a statement to that effect should be made.

Resolution Bandwidth (spectrum analyzer): The width, in Hz, of the spectrum analyzer's response to a continuous wave (CW) signal. This width is usually defined as the frequency difference at specified points on the response curve, such as the 3 or 6 dB down points. The manufacturer will specify the dB down points to be used.

Return Loss: The ratio in decibels of the power incident upon the discontinuity or the power reflected from the discontinuity.

Annex D

(Informative)

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