NRSC GUIDELINE

NATIONAL RADIO SYSTEMS COMMITTEE

NRSC-G100
Bandwidth Options for Analog AM Broadcasters
September, 2007

THIS IS AN OUTDATED VERSION

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FOREWORD

The NRSC adopted a 10 kHz standard analog AM audio bandwidth in 1986, which represented a "narrowing" of AM signals from the 15 kHz audio bandwidth which had been used up to that time. This action by the NRSC, embodied in the *NRSC-1 Standard*, came as a result of deliberations on the causes and cures of AM interference, and a desire to technically encourage the production of higher fidelity AM receivers.

Nearly twenty years later, in 2004, as part of a review of the NRSC's AM bandwidth standards, the NRSC's AMB Subcommittee recognized that some broadcasters were reducing the audio bandwidth of their analog AM signals from the 10 kHz specified by the NRSC standards to 5-6 kHz, in an effort to further reduce interference in the band, and with the understanding that most consumer receivers are bandlimited to 5 kHz or less. Further, this bandwidth reduction was being done independent of the bandwidth reduction required when a broadcaster elects to transmit a hybrid AM in-band/on-channel (IBOC) digital radio signal.

A proposal was put forth that the NRSC consider reducing the analog audio bandwidth specification to something less than 10 kHz, but the Subcommittee agreed that before such an action could be considered, a rigorous study of both analog AM receivers (characterizing, among other things, receiver bandwidth) and consumer reaction to reduced bandwidth would need to be conducted.

Consequently, in late 2004 the Subcommittee formed the AM Study Task Group (AMSTG, co-chaired by Frank Foti, Telos/Omnia and John Kean, NPR Labs) to determine whether consumers would reliably perceive the audio quality differences of AM transmissions at various bandwidths, recorded through commercially available receivers, and whether these perceptions would affect consumers' continued listening behavior. The AMSTG subsequently conducted a consumer subjective evaluation study of audio obtained from three typical receivers, as well as an objective evaluation of audio performance of a large number of current consumer analog AM receivers, including OEM and after-market car radios, shelf mini-systems, boom boxes, table radios and portables.

The information contained in this NRSC Guideline is derived from the AMSTG study report and the resulting deliberations of the AMB Subcommittee of the NRSC, co-chaired by Stan Salek, Hammett & Edison, Inc., and Jeff Littlejohn, Clear Channel Broadcasting, Inc. The NRSC chairman at the time of adoption of NRSC-G100 was Milford Smith, Greater Media, Inc.

The NRSC is jointly sponsored by the Consumer Electronics Association and the National Association of Broadcasters. It serves as an industry-wide standards-setting body for technical aspects of terrestrial over-the-air radio broadcasting systems in the United States.

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FIGURES

BANDWIDTH OPTIONS FOR ANALOG AM BROADCASTERS

1 SCOPE

This is an informative Guideline document which provides information on bandwidth options for analog AM broadcasters. The recommendations contained herein are based primarily on the results of a study conducted by the AM Study Task Group (AMSTG) of the NRSC's AMB Subcommittee. Broadcasters electing to transmit hybrid AM IBOC signals will typically limit the bandwidth of the analog portion of the signal using either the 5 kHz or 8 kHz mode as specified in the NRSC-1-A and NRSC-5-A Standards.

2 REFERENCES

2.1 Normative References

This is an informative specification. There are no normative references.

2.2 Informative References

The following references contain information that may be useful to those implementing this Guideline document. At the time of publication the edition indicated was valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

[1] *NRSC-1-A, NRSC AM Preemphasis/deemphasis and Broadcast Audio Transmission Bandwidth Specifications*, National Radio Systems Committee, September 2007
[2] *NRSC-2-A, Emission Limitation for Analog AM Broadcast Transmission*, National Radio Systems Committee, September 2007
[3] *NRSC-3, Audio Bandwidth and Distortion Recommendations for AM Broadcast Receivers*, National Radio Systems Committee (retired September 2007)
[4] *NRSC-5-A, In-band/on-channel Digital Radio Broadcasting Standard*, National Radio Systems Committee, September 2005
[5] *Consumer Testing of AM Broadcast Transmission Bandwidth and Audio Performance Measurements of Broadcast AM Receivers*, NPR Labs, September 8, 2006 (also included as ANNEX 1 to this Guideline)
[6] *Summary Report: Consumer Testing of AM Broadcast Transmission Bandwidth and Audio Performance Measurements of Broadcast AM Receivers*, NRSC AMB Subcommittee, December, 2006

2.3 Informative Reference Acquisition

Documents [1]-[6] are distributed free of charge via the NRSC website at: http://www.nrscstandards.org

2.4 Symbols and Abbreviations

In this Guideline the following abbreviations are used.

AM	Amplitude Modulation
AMSTG	AM Study Task Group (of the NRSC AMB Subcommittee)
NRSC	National Radio Systems Committee
FCC	Federal Communications Commission (U.S.)
FM	Frequency Modulation
IBOC	In-Band/On-Channel
N/A	Not Applicable
RF	Radio Frequency
TBD	To Be Determined

2.5 Definitions

In this Guideline the following definitions are used.

Audio bandwidth	The maximum bandwidth of the audio signal input to an AM transmission system, indicated as a positive number such as *10 kHz.* The term is employed in a general sense, unless a specific low-pass filter curve is specified.
HD Radio™	Trademark (of iBiquity Digital Corporation) for the digital AM and digital FM transmission technology authorized by the FCC. Note that the use of the term “HD Radio” in the NRSC-5-A Standard and its normative references shall be interpreted as the generic term “IBOC” for the NRSC-5 compliant system and shall not be construed as a requirement to adhere to undisclosed private specifications that are required to license the HD Radio name from its owner.
Signal bandwidth	The maximum bandwidth of the AM radio frequency signal, which is twice the audio bandwidth and may be represented as a positive number, such as *20 kHz*, representing the amount of spectrum occupied by the upper and lower sidebands of the AM signal, or as a dual-signed number, such as ±*10 kHz*, representing the maximum offset of the sidebands from the RF carrier frequency.

3 BACKGROUND

3.1 AM band adjacent channel interference problem

Broadcast signals in the U.S. occupying the AM band (535-1705 kHz) are potentially subject to significant adjacent channel interference by virtue of the fact that, while each signal is 20 kHz wide (± 10 kHz), AM stations are allocated at 10 kHz intervals.[1] This situation becomes particularly problematic during nighttime hours because RF signals in this frequency band are subject to a phenomenon known as skywave propagation, in which they travel longer distances at night by reflecting off the earth's ionosphere.[2]

This situation is illustrated in the figures below for the case of analog AM transmissions. Figure 1 shows the FCC's analog AM mask (dashed line) versus frequency and the relationship of that mask to an analog AM signal utilizing the current NRSC-standard 10 kHz audio bandwidth.[3] (Note that the RF signal is actually 20 kHz wide since AM broadcasts utilizes double-sideband amplitude modulation.)

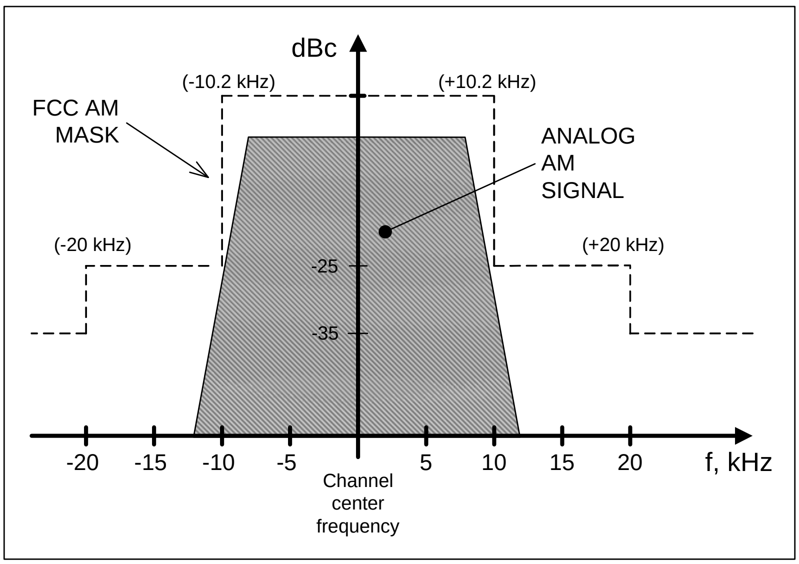


Figure 1. FCC analog AM mask

Figure 2 shows a hypothetical AM station received by Listener A, in City A, and another for Listener B in City B. As shown in the figure, Listener A can receive a station on 930 kHz during the day with no significant undesired signal energy impinging upon it. Likewise, Listener B has undiminished reception of a station on 940 kHz.

During daytime hours, when there is only groundwave propagation of the AM signals, Listeners A and B do not receive interference from Cities B and A, respectively. This is true even when these stations are broadcasting signals that have the full, 10 kHz NRSC-specified bandwidth for analog AM transmissions.

[1] Hybrid AM IBOC signals are wider than this, extending out to ±15 kHz, but still fall within the mask shown in Figure 1. The interference implications of these wider IBOC signals is discussed in Section 3.5.
[2] Signals that propagate via the ionosphere, called skywaves, can provide significant signal strength at distances up to a few thousand kilometers. See *Propagation Characteristics of Radio Waves*, NAB Engineering Handbook 10th Edition, Chapter 1.8, Focal Press, 2007, for more information.
[3] See §73.44 of the FCC rules and NRSC-2-A. A different mask applies to hybrid AM IBOC signals; see NRSC-5-A and §73.404(a) of the FCC rules.

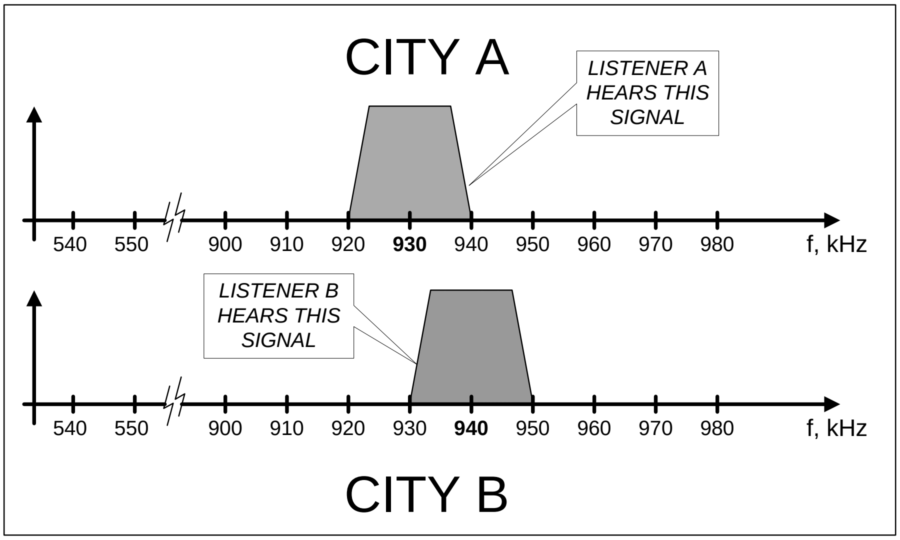


Figure 2. Daytime reception of two hypothetical stations by listeners in two cities

At night, when skywave propagation is present, skywave signals on adjacent channels flood each listener's receiver. The 940 kHz signal from City B is received by Listener A; the 930 kHz signal from City A is received by Listener B (see Figure 3). Because the ±10 kHz sidebands of the two stations overlap, both Listener A and Listener B may experience interference that cannot be filtered out of the receiver. The overlapping spectra in Figure 3 represent the first-adjacent channel interference situation resulting from 20 kHz-wide signals being allocated on a 10 kHz spacing.

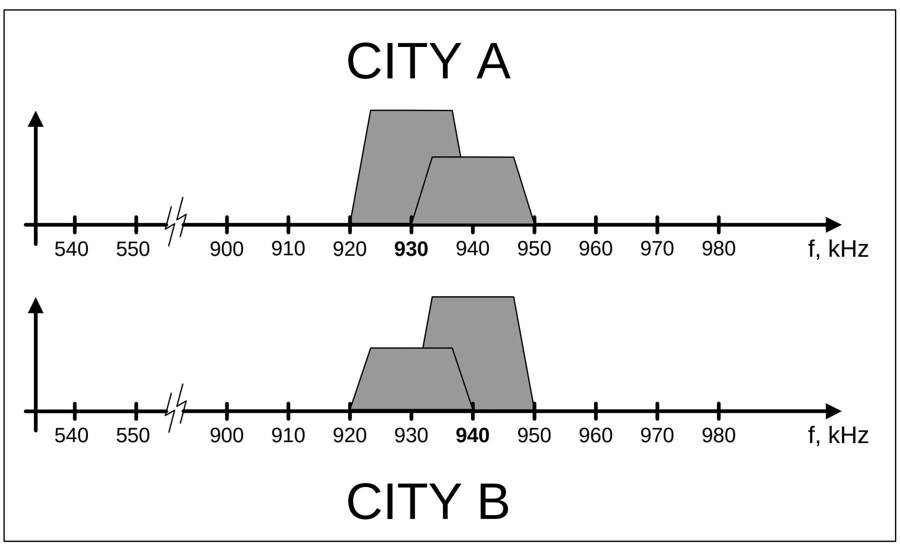


Figure 3. Illustration of interference from adjacent channel overlap of skywave signal – ±10 kHz signals, nighttime

The complexity of skywave interference becomes more apparent when we realize that there are stations on all frequencies whose skywave signals are propagating great distances at night. Figure 4 illustrates the arrival of skywave signals from City C and City D on 920 and 950 kHz. Listener A and Listener B each suffer additional skywave interference on the other adjacent channel (920 kHz for Listener A and 950 kHz for Listener B).

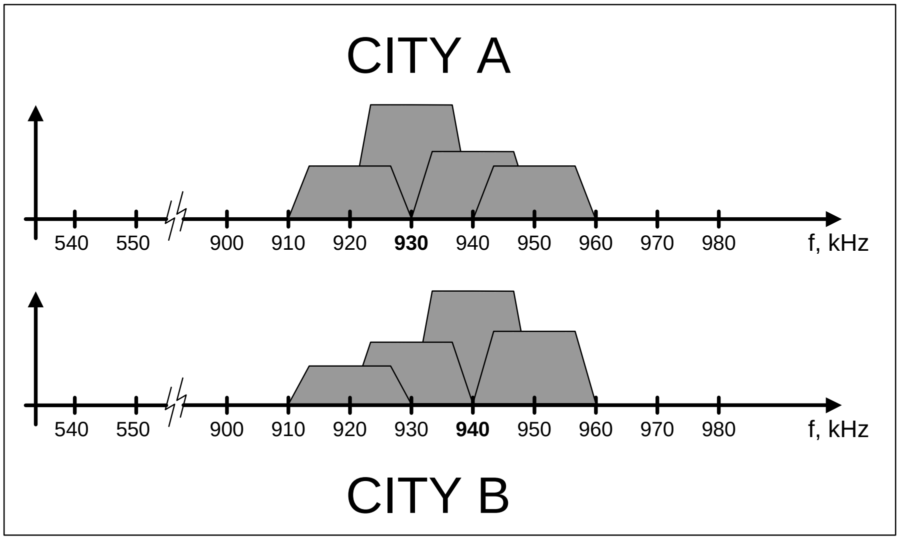


Figure 4. Illustration of interference from adjacent channel overlap of skywave signals from multiple stations – ±10 kHz signals, nighttime

This interference situation caused by first adjacent channel skywave signal overlap can be remedied by reducing all analog signal bandwidths from ±10 kHz to ±5 kHz as shown in Figure 5. With the reduced bandwidth signals, the overlap among adjacent spectra (which is the primary source of first adjacent channel interference) is eliminated. Note that because of the 10 kHz channel spacing, the 5 kHz bandwidth represents the greatest bandwidth for which there is no first-adjacent channel energy overlap between signals.

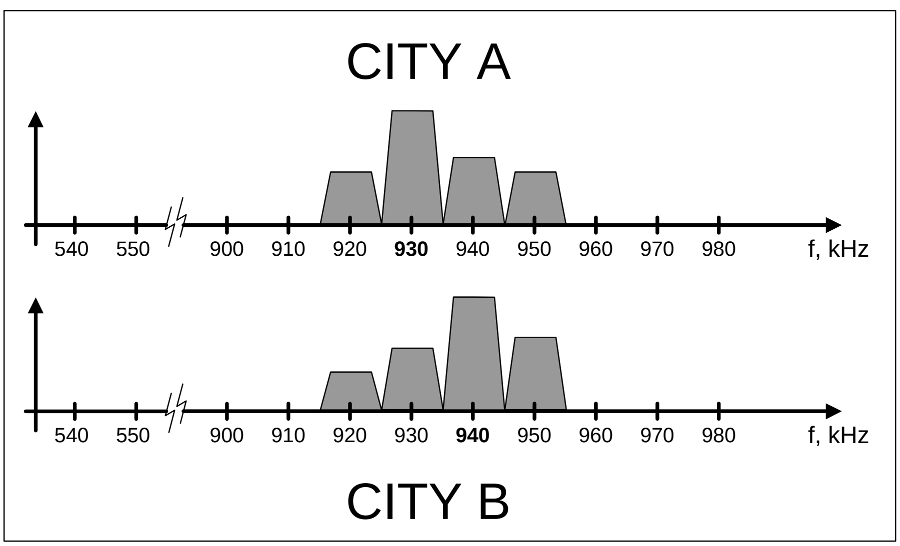


Figure 5. Elimination of first adjacent channel energy overlap in skywave reception conditions – ±5 kHz signals, nighttime

3.2 Receiver bandwidth and the NRSC AM standards

In adopting the NRSC-1, -2, and -3 Standards, one of the goals of the NRSC was to foster the development of “wideband” AM radios, that is, AM radios that implemented a full 10 kHz-wide signal path, allowing for the full audio fidelity of the 10 kHz signal being broadcast to be heard by the listener.

In 1992, NRSC sponsoring organizations NAB and CEA introduced "AMAX," a certification program for AM radio receivers that met the technical specifications of NRSC-3, and that also exhibited other desirable characteristics.[4] Those included adjustable reception bandwidth and the availability of an external antenna connection. Further, receivers meeting all of these conditions that also had stereo reception capability could use the designation "AMAX Stereo." Automotive receivers were granted limited relief to the bandwidth requirement, such that radios exhibiting at least a 6.5 kHz bandwidth could still receive certification.

Receiver manufacturers, however, have elected to use narrowband filters in the vast majority of modern consumer receivers (as discussed in Section 3.3 below, the average 3 dB bandwidth of consumer receivers as measured by the NRSC’s AMSTG is approximately 2.5 kHz). The reason for this is that the narrowband filters reject the majority of the first-adjacent channel interference (shown in Figure 6) and natural and man-made noise which exists in the AM band. Available data indicate that listeners prefer reduced interference and reduced audio bandwidth (provided by the narrowband filter) over greater interference and greater audio bandwidth (provided by wideband filters), as discussed in the sections following.

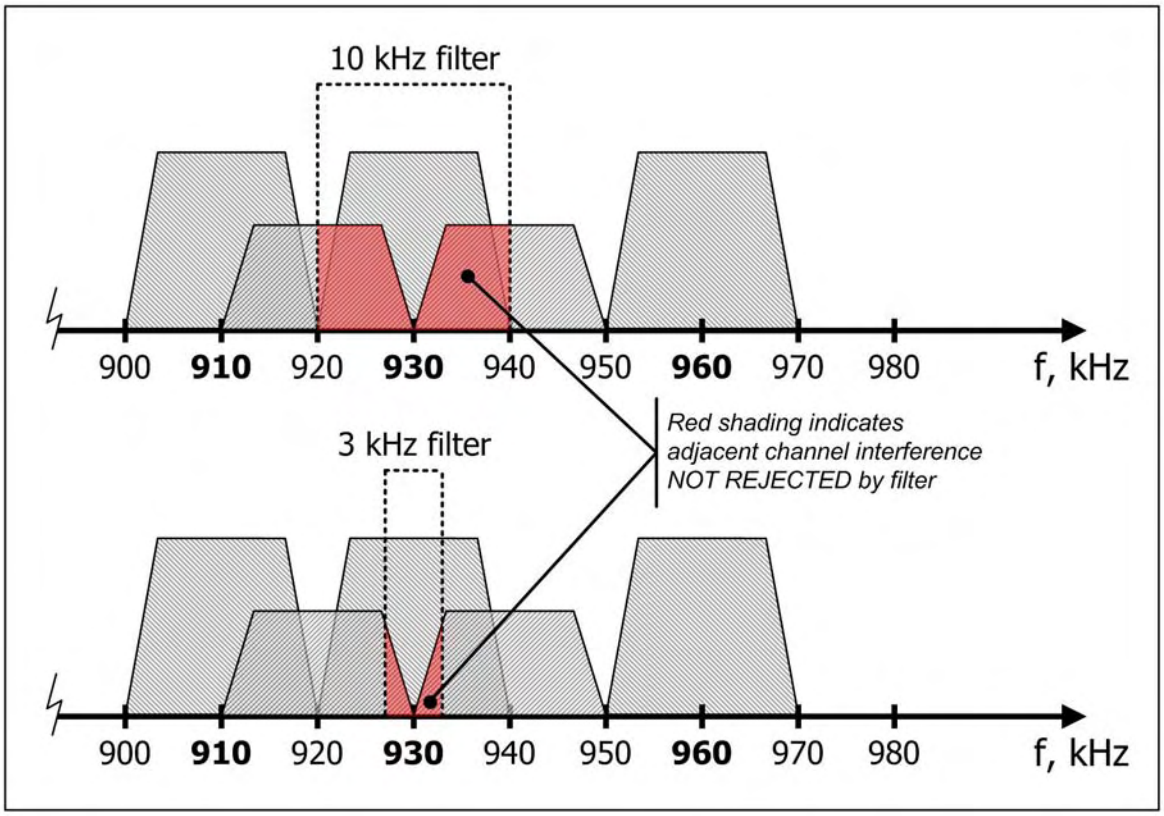


Figure 6. Illustration of the rejection of adjacent channel interference as a function of receiver filter bandwidth.

[4] NRSC-3 was retired by the NRSC in September 2007.

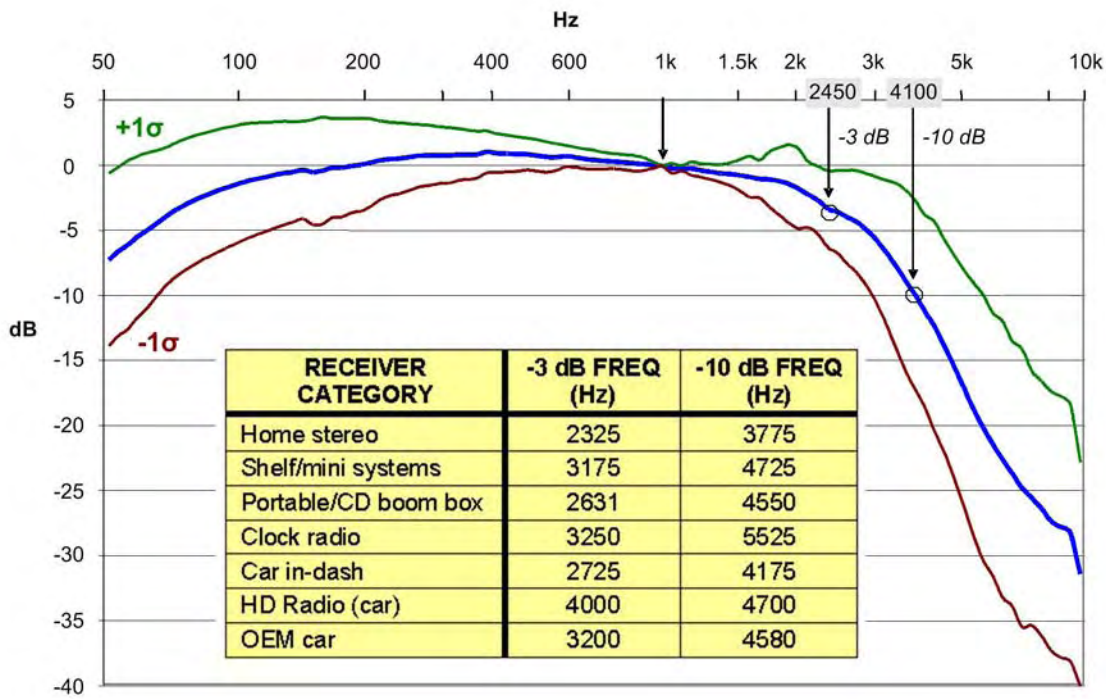
3.3 AMSTG report – receiver characterization

Objective measurements of 30 consumer analog AM receivers were completed in late 2005 with support from the Consumer Electronics Association (CEA) and the National Association of Broadcasters (NAB; CEA and NAB are the co-sponsors of the NRSC).[5] These laboratory measurements, conducted by NPR Labs, collected data in two areas:

- Baseline audio performance of the receivers, including frequency response, harmonic distortion, intermodulation distortion and signal to noise ratio;
- Objective noise level differences with signal interference at several audio transmission bandwidths (i.e., 5, 6, and 7 kHz), relative to the current transmission bandwidth standard of 10 kHz. Weighted quasi-peak noise measurements were taken to approximate the response of human hearing to audible noise. A first-adjacent channel (±10 kHz) interfering signal was modulated with a pulsed frequency-shaped noise to simulate the characteristics of program audio.

3.3.1 <u>Receiver bandwidth measurements</u>

These objective measurements established that the majority of current analog AM receivers have audio bandwidths of less than 5 kHz. In fact, with only a few exceptions, the frequency response of individual receivers falls off above 1 or 2 kHz. As shown in Figure 7, the combined frequency response of all receivers through the test bed (the middle curve, in blue) was 3 dB at 2450 Hz and 10 dB at 4100 Hz.



RECEIVER CATEGORY	-3 dB FREQ (Hz)	-10 dB FREQ (Hz)
Home stereo	2325	3775
Shelf/mini systems	3175	4725
Portable/CD boom box	2631	4550
Clock radio	3250	5525
Car in-dash	2725	4175
HD Radio (car)	4000	4700
OEM car	3200	4580

*Figure 7. AM frequency response mean and standard deviation (1**σ**) curves for all measured receivers*

The overall variation in audio bandwidths was wide, as shown by the standard deviation for the entire test population (+1σ in green and -1σ in brown): at 4100 Hz, the first-order standard deviation was approximately -2.6 dB and -17.2 dB, a range of 14.6 dB. The table inset in Figure 7 lists the 3 dB and 10 dB bandwidths for the receivers by category.

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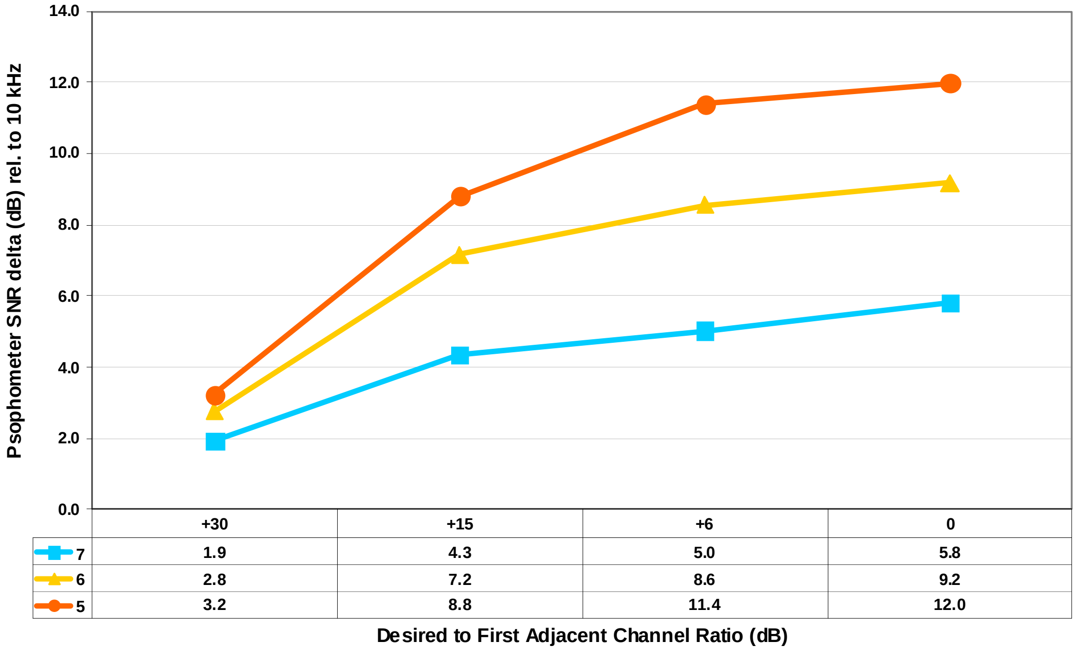
[5] See normative reference [5], starting on pg.24.

3.3.2 Impact of transmission bandwidth on signal-to-noise ratios

Further, each receiver was evaluated for change in noise (at the audio output) with 1st-adjacent channel interference using audio transmission bandwidths of 5, 6, 7 and 10 kHz at desired-to-undesired RF signal ratios of 30, 15, 6 and 0 dB. The effect of transmission bandwidth on weighted quasi-peak SNR for the combined receivers is summarized in Figure 8, showing that reduced transmission bandwidth offers SNR improvements of up to 12 dB, relative to 10 kHz bandwidth, with 1st-adjacent channel interference.



	+30	+15	+6	0
7	1.9	4.3	5.0	5.8
6	2.8	7.2	8.6	9.2
5	3.2	8.8	11.4	12.0

Figure 8. Effect of transmission bandwidth on received SNR

3.4 AMSTG subjective broadcast industry and consumer testing

Based on the findings of the receiver measurements, subjective testing was conducted, by Sheffield Audio Consulting and NPR Labs, in two phases between February and May, 2006, using audio recorded from three of the tested receivers.[6] Because it was necessary, as a practical matter, to limit the number of bandwidths tested in the consumer study, the AMSTG decided to use three bandwidths: 10 kHz (current NRSC standard bandwidth and maximum bandwidth allowed under current FCC rules), 5 kHz (represents the maximum bandwidth where adjacent channels do not overlap) and an intermediate bandwidth. To establish this intermediate bandwidth, a "phase 1" listening test was conducted in which 18 broadcast industry representatives participated; it was subsequently determined that 7 kHz was the best intermediate bandwidth, between 5 kHz and 10 kHz, to be included in the consumer test.

In the "phase 2" listening test, consumers judged the following:

(a) which transmission bandwidth, 5 kHz, 7 kHz or 10 kHz, had the best quality,
(b) the magnitude of the difference between the quality experienced using these bandwidths, and
(c) whether they would continue to listen to the audio, given the quality of each of the samples.

Audio samples used in this phase 2 test included those impaired by 1st-adjacent channel interference in addition to unimpaired reception. Audio source material was taken from NRSC music test samples, NPR

[6] See normative reference [5], starting on pg. 6.

speech samples, a sportscast and commercials supplied by Greater Media, Inc. Forty-four listeners participated in the consumer test, distributed between 19 and 71 years of age. Data from 40 qualified listeners—20 female and 20 male—was collected.

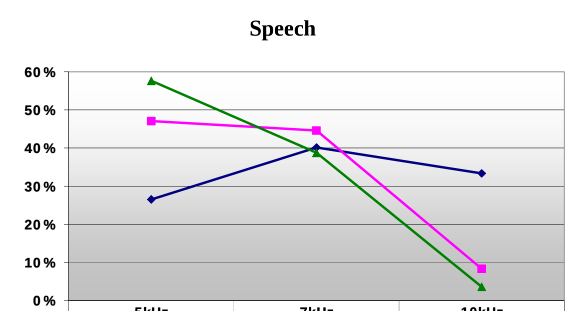
As previously noted, audio samples were recorded from three receivers selected from the pool of those that were objectively tested. The three receivers selected were the JVC KS-FX490 car in-dash cassette (median-bandwidth), the Panasonic CQ-CB9900U in-dash CD/HD Radio (80th percentile bandwidth) and the Aiwa JAX S77 portable boom box (20th percentile bandwidth).

Because differences in audio quality among bandwidths were often small, an A/B pair-wise comparison was the appropriate method to use for obtaining listener's judgments. Test participants listened to seven different samples (recorded under a variety of conditions), including female and male speech, voice-over (commercial), a sportscast, and rock, country and classical music. Over the course of the entire test, participants listened to a total of 189 sample pairs. After listening to each sample pair, consumers were asked to judge which sample they thought had better quality, how big the quality difference between samples was, and whether they would continue to listen to the audio for either or both of the samples.

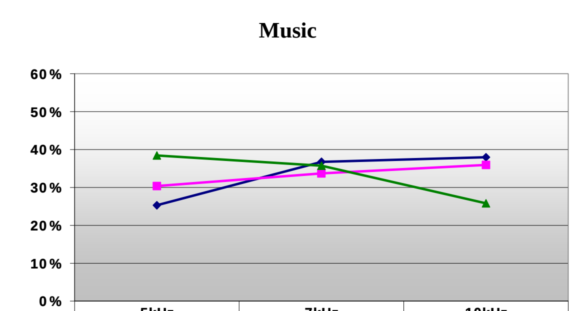
The graphs in Figure 9 show the percentage of participants who picked one bandwidth over another (e.g., 5 kHz over 10 kHz) at various D/U signal conditions, separated by genre (i.e., speech, music, commercial and sportscast) and aggregated for the three receiver bandwidths tested (20th percentile, median and 80th percentile bandwidth). Because participants were asked to choose which sample ("A" or "B") had better quality and there were three combinations of forced-choice pairs (i.e., 5 kHz vs. 7 kHz; 7 kHz vs. 10 kHz; 5 kHz vs. 10 kHz), 33% represents the level of responses that would be considered "at chance." Any positive or negative difference from 33% of 12 percentage points or more (i.e., percentages greater than 45% or less than 21%) can be considered significantly different from chance. Thus, finding that less than 21% or more than 45% of respondents preferred a particular bandwidth in an individual condition should be considered significant.

Consumer subjective test results suggest the following:

- For music, commercials and sportscasts, little difference was heard between 7 and 10 kHz bandwidths, regardless of 1st-adjacent channel interference conditions. For speech, which does not mask noise and interference, larger differences were perceived, based on impairment conditions;
- In unimpaired or moderately impaired conditions (as determined by the desired-to-undesired signal ratio, D/U), people tended to prefer higher bandwidths to lower bandwidths. However, 7 kHz and 10 kHz bandwidths had equal preference;
- With speech in moderate to heavy impairment conditions, participants preferred lower bandwidths (5 kHz and 7 kHz) to higher bandwidths, despite a mutual reduction in transmission bandwidth on the desired channel.



	5kHz	7kHz	10kHz
30dB	27%	40%	33%
15dB	47%	45%	8%
6dB	58%	39%	4%



	5kHz	7kHz	10kHz
30dB	25%	37%	38%
15dB	30%	34%	36%
6dB	38%	36%	26%

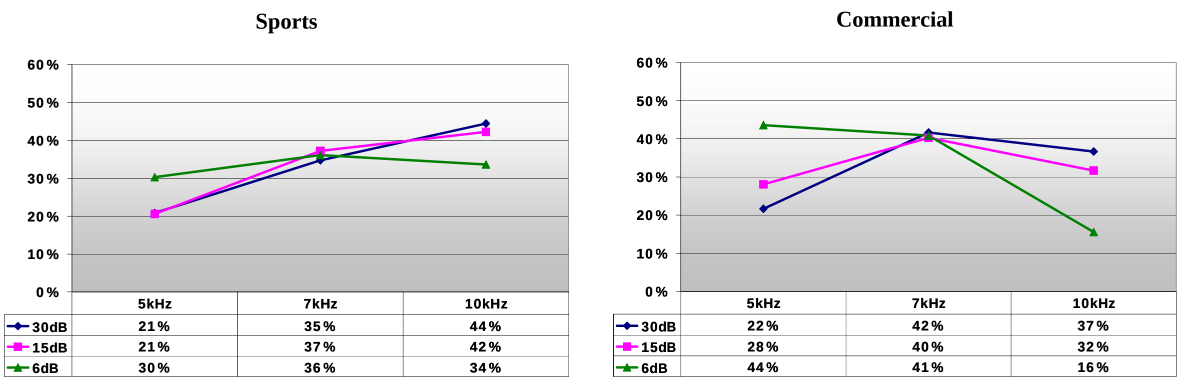


Figure 9. Percentages of listeners who picked one bandwidth over another, by genre, with no 1st-adjacent channel interference (30 dB), moderate 1st-adjacent channel interference (15 dB), and heavy 1st-adjacent channel interference (6 dB)

Overall, although there was some variation in preference between genres and D/U ratios, these data suggest that in general consumers preferred lower bandwidths (between 5 kHz and 7 kHz) to higher bandwidths. In the majority of listening conditions, consumers preferred either 5 kHz or 7 kHz, and often reported that 7 kHz was equivalent to 10 kHz in unimpaired or moderately impaired conditions. These preferences were articulated most strongly in speech conditions, where noise from interference affected listeners the most.

In extrapolating this consumer data to general public listening, it is important to note that discerning background noise is easiest in speech conditions, and thus the speech testing represent the most critical results. This is important for two reasons: (a) the majority of AM programming includes speech, and (b) consumers will hear more noise in any music, sports, and commercials that are qualitatively less "dense" than the programmatic material included in this test. Since consumers seem to be most critical of "noise" and seem to tolerate more constrained bandwidth when they receive a clean signal, it is likely that lower bandwidths will satisfy consumers in most conditions.

3.5 Interference considerations of hybrid AM IBOC signals

The FCC, in October 2002, authorized the transmission of hybrid AM IBOC signals during daytime hours, and then in March 2007 extended this authorization to nighttime hours as well.[7] While still falling within the FCC analog AM mask (Figure 1), these hybrid AM IBOC signals extend out to ±15 kHz and as a result may potentially increase adjacent channel interference in the AM band.

NRSC-5-A specifies two different operational modes for hybrid AM IBOC which differ only by the bandwidth of the analog portion of the signal—these are the 5 kHz mode (Figure 10) and 8 kHz mode (Figure 11). Note that these figures are not to scale, and that the digital subcarrier portions of the signal are actually 13 dB weaker than the analog portion.

[7] See *Second Report and Order, First Order on Reconsideration and Second Further Notice of Proposed Rulemaking*, MM Docket No. 99-325, released May 31, 2007, paragraph 89.

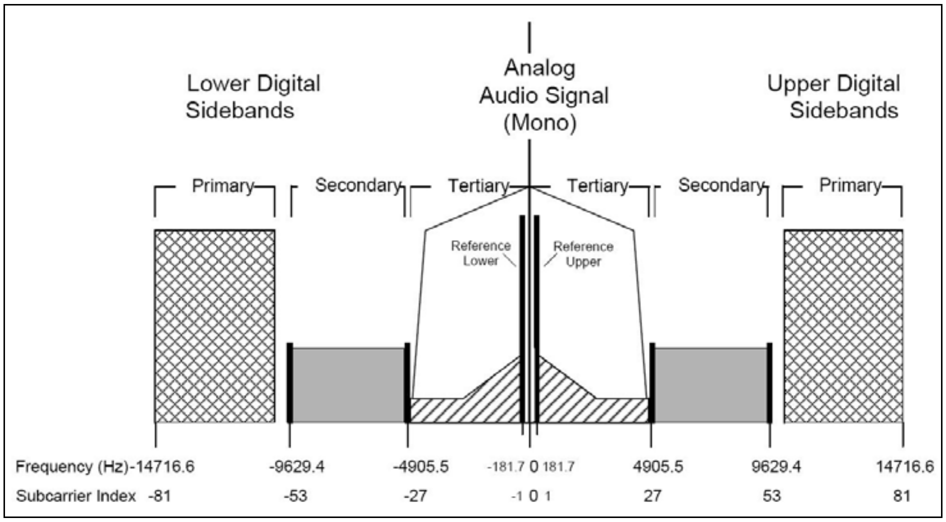


Figure 10. Hybrid AM IBOC spectrum – 5 kHz analog signal bandwidth[8]

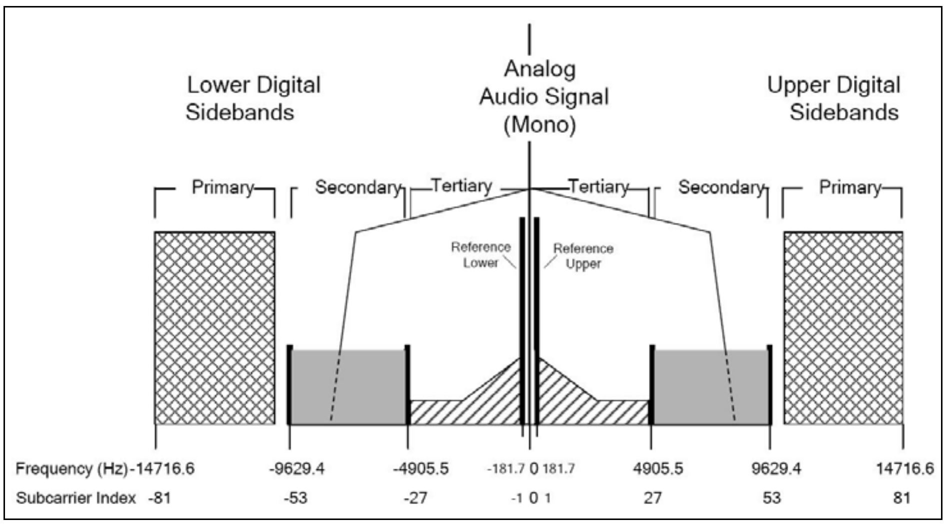


Figure 11. Hybrid AM IBOC spectrum – 8 kHz analog signal bandwidth[9]

The fact that these signals, specifically, the digital subcarriers, would potentially increase the adjacent channel interference in the band was recognized by the NRSC in its evaluation of the iBiquity AM IBOC system:

> *In order to enjoy the dramatic improvements that AM IBOC has to offer, AM broadcasters must consider a system specific trade-off. AM IBOC places digital carriers up to 15 kHz on either side of an AM station's main carrier. NRSC tests confirmed that a station transmitting an IBOC signal encounters very little, if any, interference to its own received signal. Although the IBOC digital*

[8] Source: *HD Radio Air Interface Design Description – Layer 1 AM*, Figure 5-1, Doc. SY_IDD_1012s, Rev. E, March 12, 2005, iBiquity Digital Corporation.
[9] Source: *HD Radio Air Interface Design Description – Layer 1 AM*, Figure 5-2, Doc. SY_IDD_1012s, Rev. E, March 12, 2005, iBiquity Digital Corporation.

> *carriers operate at very low power levels, in some cases stations on first adjacent channels may receive noticeable interference under certain listening conditions.*[10]

While there is no requirement that analog AM broadcasters modify transmission bandwidth to be compatible with IBOC transmissions, broadcasters who continue to transmit analog AM signals may have additional incentive to consider operating at a bandwidth less than 10 kHz. In doing so, they will be helping to reduce the energy in adjacent channels and they will also be making their signals more robust to potential interference by concentrating their signal energy within the passband of the narrowband analog AM receivers now prevalent in the marketplace.

[10] See *DAB Subcommittee, Evaluation of the iBiquity Digital Corporation IBOC System, Part 2 – AM IBOC*, pg. 8, National Radio Systems Committee, April 6, 2002.

4 AM ANALOG OPERATION WITH PASSBANDS LESS THAN 10 kHz

Given the results of the AMSTG study, broadcasters may want to consider reducing the audio bandwidth of their analog AM signals to as little as 5 kHz. The principal benefits obtained by doing this are the following:

- ***Listener preference*** – overall, although there was some variation in preference between genres and D/U ratios, the AMSTG study data suggest that in general consumers preferred lower bandwidths (between 5 kHz and 7 kHz) to higher bandwidths. In the majority of listening conditions, consumers preferred either 5 kHz or 7 kHz, and often reported that 7 kHz was equivalent to 10 kHz in unimpaired or moderately impaired conditions;

- ***Reduced adjacent channel interference*** – every broadcaster who elects to transmit a signal narrower than ±10 kHz will be reducing the overall amount of adjacent channel interference in the AM band. This is illustrated in Figure 12 for the case where analog signal bandwidth is reduced from 10 kHz to 7 kHz;

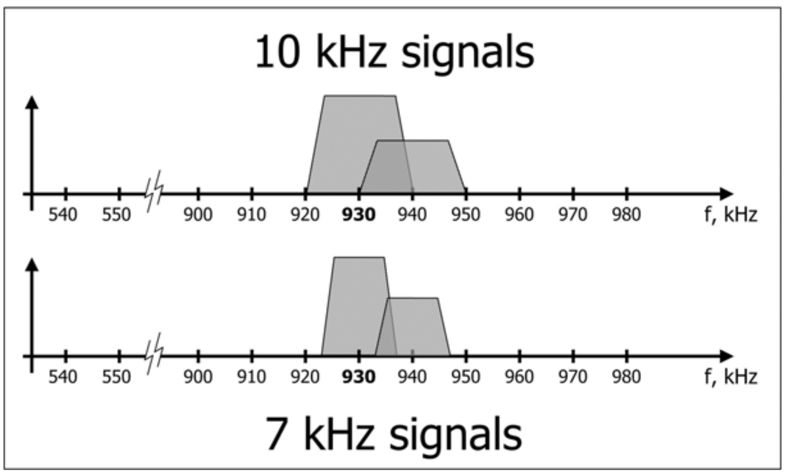


Figure 12. Illustration of reduction in first-adjacent channel interference when reducing signal bandwidth from 10 kHz to 7 kHz – the region of overlapped spectra represents the amount of adjacent channel interference in each case

- ***Improved signal-to-noise ratio*** – given that the majority of consumer receivers have audio bandwidths less than 5 kHz, by concentrating the energy of the AM signal into a narrower bandwidth, more of this energy will pass through the receiver filter and the listener should experience a louder, cleaner signal with greater signal-to-noise ratio compared to the same AM signal broadcast with a ±10 kHz bandwidth.

The only disadvantage to reducing the transmitted AM signal bandwidth is that the listener using a wideband receiver will have no wideband audio to listen to, but since wideband receivers comprise only a small fraction of the receiver population the impact of this should be minimal.[11]

Reduction of transmitted audio bandwidth below 5 kHz is not recommended since this would begin to constrain the audio to a quality more representative of telephone communications. While some receivers severely filter the audio below 5 kHz already, it is the elimination of the channel overlap energy with 5 kHz

[11] Broadcasters should note that the reception bandwidth of test equipment and modulation monitors is not representative of the majority of consumer receivers – see Figure 7.

transmitted audio bandwidth that is believed to provide the greatest reduction in interference across the AM band. If the majority of stations adopt narrower bandwidths, not only does it reduce interference, but it also may encourage more receivers to be designed to take advantage of the reduced interference by increasing their bandwidths to 5 kHz.

4.1 AM transmission preemphasis for analog AM systems with passband less than 10 kHz

AM preemphasis is the boosting of high audio frequencies prior to modulation and transmission. Section 5 of NRSC-1-A describes a standard preemphasis curve and it is recommended that this standard curve should be utilized even when transmission bandwidths are less than ±10 kHz.

Specifically, the preemphasis characteristic described in NRSC-1 should be truncated without scaling for use with narrower bandwidths. This recommendation presumes that the majority of the AM receivers in use by consumers have been implemented using the NRSC-standard deemphasis curve (also described in NRSC-1), so using this preemphasis curve as published, regardless of the actual audio bandwidth employed, maintains optimum matching between preemphasis and deemphasis.

4.2 Audio envelope stopband attenuation for analog AM systems with passband less than 10 kHz

It is recommended that the specification for the audio envelope input spectrum to an AM transmitter given in Section 7.2 of NRSC-1-A be met for the stopband portion of the audio filters used in an AM system operating with a bandwidth less than 10 kHz. Specifically, the system bandwidth should smoothly transition from the cutoff frequency (assumed to be less than that specified in NRSC-1-A) to levels at or below those specified in Section 7.2 of NRSC-1-A.

4.3 RF mask for analog AM systems with passband less than 10 kHz

FCC rules (47 CFR 73.44) require that all analog AM transmissions meet the RF mask, which is similar to the maximum occupied RF bandwidth given in Section 4.2 of NRSC-2-A. It is recommended that, if practicable, the RF mask be applied in a manner that shifts the ±10 kHz starting points of the mask to the new narrower bandwidth limit. For instance, if 5 kHz were the new audio bandwidth, the mask would start at ±5 kHz, drop to -25 dBc from 5 to 10 kHz, then the remainder of the mask, as published, would apply (Figure 13). If not practicable, then it is recommended that systems with a passband less than 10 kHz utilize transition bands that are as steep and selective as practicable so as to minimize the energy overlap between adjacent channels.

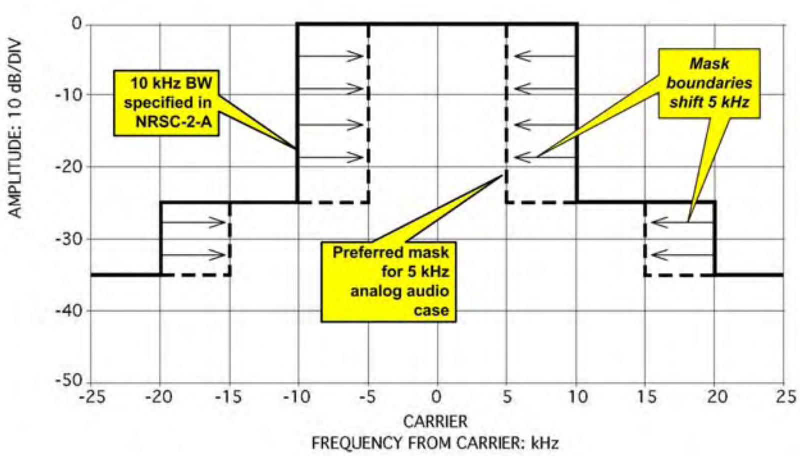


Figure 13. Illustration of preferred reduction of RF mask for example in Section 4.3

NRSC Document Improvement Proposal

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ANNEX 1 -
CONSUMER TESTING OF AM BROADCAST TRANSMISSION BANDWIDTH AND AUDIO PERFORMANCE MEASUREMENTS OF BROADCAST AM RECEIVERS

Prepared for the AM Study Task Group, AMB Subcommittee, National Radio Systems Committee

NPR Labs, September 8, 2006

Consumer Testing of AM Broadcast Transmission Bandwidth and Audio Performance Measurements of Broadcast AM Receivers

Prepared for the AM Study Task Group,

AMB Subcommittee,

National Radio Systems Committee

September 8, 2006

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Table of Contents

1 Executive Summary

This study was conducted to determine whether consumers reliably perceive audio quality differences of AM transmissions at various bandwidths, recorded through commercially available receivers, and whether these perceptions would lead consumers to change their listening behavior.

Under the supervision of the NRSC's AM Study Task Group, laboratory measurement of consumer AM receivers was completed in late 2005, establishing that the majority of these receivers have audio bandwidths of 5 kHz or less. Based on those findings, subjective testing was designed and conducted in two phases between February and May, 2006. In Phase 1, "broadcast-industry" participants determined an intermediate bandwidth, between 5 kHz and 10 kHz,[1] to be included in the consumer test (7 kHz was selected). In Phase 2, consumers judged which transmission bandwidth at 5 kHz, 7 kHz or 10 kHz had better quality, the magnitude of the differences and whether they would continue to listen to the radio, given the quality of each of the samples. Testing included audio samples impaired by first-adjacent channel interference in addition to unimpaired reception. Consumer test results suggest the following:

- Perceived differences in audio quality between 5, 7, and 10 kHz bandwidth were small for most genres. For music, commercials and sportscasts, little difference was heard between 7 and 10 kHz, regardless of adjacent channel interference conditions. For speech, which does not mask noise and interference, larger differences were perceived, based on impairment conditions.

- In unimpaired or slightly impaired conditions (as determined by the desired-to-undesired signal ratio, D/U), people tended to prefer higher bandwidths to lower bandwidths. However, 7 and 10 kHz had equal preference.

- With speech in moderate to heavy impairment conditions participants preferred lower bandwidths (5 and 7 kHz) to higher bandwidths, despite a mutual reduction in transmission bandwidth on the desired channel.

- The data suggest that the rather substantial "turn-off" rate with heavy impairment can be ameliorated by using a lower transmission bandwidth.

Overall, although there was some variation in preference between genres and D/U ratios, the data strongly suggest that in general consumers preferred lower bandwidths (between 5 and 7kHz) to higher bandwidths.

[1] 10 kHz is the bandwidth specified in NRSC Standards –1, -2, and –3, and is also the maximum transmission bandwidth allowable under FCC rules.

2 Subjective Testing of AM Transmission Bandwidth

2.1 Introduction

The primary goals of this study were to determine whether (a) consumers would reliably perceive audio quality differences of AM transmissions at various bandwidths, as recorded through commercially available receivers, and (b) whether these perceived differences would lead consumers to change their listening behavior. Because it would not be feasible in one study to have consumers listen to all possible bandwidths, the AMSTG decided early in the design process to limit presentation to three bandwidths:10 kHz, 5 kHz and an intermediate bandwidth, which was determined by an independent pilot study.[2]

This document describes results from three independent studies, designed to shed light on the primary goals identified above. It is divided into 3 sections: (a) Phase 1 - results from a broadcast-industry listener test, designed to determine the third bandwidth that would be included in the consumer test (7 kHz was selected); (b) Phase 2 - results from a consumer test, conducted in April and May, 2006; and (c) results from objective audio performance measurements of consumer receivers conducted at NPR Labs (during fall of 2005).

Specific goals of the broadcast-industry participant listening test included:

- Selecting an intermediate bandwidth between 5 and 10 kHz that would be used in the consumer test. This was necessary to limit the number of test conditions ultimately presented to general public listeners.

- Providing mean opinion scores of unimpaired transmissions and impaired transmissions at +6 dB and +15 dB with first-adjacent channel interference.

Specific goals of consumer testing included:

- Determining whether listeners preferred the NRSC and FCC-specified audio response (10 kHz) or reduced (5 kHz or 7 kHz) audio bandwidth in impaired transmission conditions (+6 dB, +15 dB and +30 dB D/U ratios)

- Determining how large perceived differences were

- Exploring the conditions under which consumers would change their behavior (keep listening or turn the radio off).

Specific goals of objective testing included:

- Documenting the audio bandwidth and other performance characteristics of currently available AM receivers by measuring a representative sample of units;

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[2] 10 kHz is the bandwidth specified in NRSC Standards –1, -2, and –3, and is also the maximum transmission bandwidth allowable under FCC rules; 5 kHz represents the maximum bandwidth which can be used without adjacent-channel AM signals "overlapping."

- Relative to 10 kHz audio transmission bandwidth, measuring the change in adjacent-channel RF interference with sample receivers at reduced audio cutoff frequencies.

Broadcast-industry participant testing was conducted at multiple locations in the United States and Canada. Participants included audio engineers, station managers and engineers. Consumer testing was conducted at Salisbury University, and included consumers between the ages of 19 and 71. Objective testing was conducted at NPR Labs, Washington, DC.

2.1.1 Filters used in testing

The Orban Optimod 9200 Digital AM Processor and Telos-Omnia 5EX-HD Processor, which are used commonly by the broadcast industry, were operated with standard broadcast settings to prepare the audio used in the listening tests. The identity of the processor for desired and undesired RF channels was known only to the NPR Labs staff.[3] The transmission bandwidths (10, 7 and 5 kHz) were determined by the lowpass filters provided in the processors. Measurements of the processors under active processing are illustrated in Appendix M. Preemphasis for the 10 kHz bandwidth was the modified 75 microsecond curve specified in NRSC-1. For 5 and 7 kHz bandwidth the preemphasis was truncated by the filter cutoff frequency.

The lowpass filter frequency had the dominant effect on both objective and subjective measurements, compared to the preemphasis characteristic. Under program conditions, the multiband processing and high-frequency peak limiters in the processors tend to control the transmitted spectral content. The same settings were used for these processor systems at each transmission bandwidth, however, it is possible that a new combination of settings for multiband processing, preemphasis and high-frequency limiting could be subjectively more optimal at lower transmission bandwidths.

2.2 Audio material for test program

For both subjective tests, audio source material was taken from NRSC music test samples, NPR speech samples, a sportscast and commercials from Greater Media, Inc. Two principles guided the selection of the genres used for these studies. First, after listening to several recordings with the test receivers in unimpaired conditions, it became evident that the difference in audio quality between 10 kHz and 5 kHz was extremely small in some cases (e.g., speech) and large in other cases (e.g., music). Secondly, current AM programming is dominated by speech, sports, commercials and country music, but future AM programming may include other musical styles as well. Therefore, we felt it prudent to include recordings from a wide variety of genres (Table 1).

Audio samples were recorded through the test bed at NPR using industry-standard processors with manufacturer's recommended settings. One processor was used for the desired signal; the other was used for the undesired signal. The recording test bed was

[3] Each of the processors were tested experimentally with the desired and undesired RF channel; NPR Labs observed no significant difference in transmission characteristics with either unit and they were considered interchangeable.

identical to the one used in objective testing, documented in Appendix A. NPR engineers and Ellyn Sheffield parsed, edited and leveled samples to ensure consistency across samples and trials.

Table 1. Source audio material used in subjective evaluations

No.	Description	Source	Test(s) used in: Pilot	Test(s) used in: Consumer
1	Commercial female	Sun Sounds of Arizona	✔	✔
2	Commercial male	Sun Sounds of Arizona	✔	
3	Garth Brooks sample 1		✔	✔
4	NRSC Cole		✔	
5	NRSC Firebird		✔	✔
6	NRSC Santana		✔	✔
7	Speech Female	NPR Reading Services	✔	✔
8	Speech Male	NPR Reading Services	✔	✔
9	Sports Baseball	Greater Media	✔	✔

2.3 Phase 1: Broadcast-Industry Participant Test

2.3.1 Methodology

In order to obtain information from a variety of industry participants, Phase 1 testing included broadcast industry personnel from all over the United States and Canada. Participants took the test at their home or office location. Participants received through the mail a CD containing 55 play lists, experimental instructions (see Appendix B), a pair of Sennheiser HD-201 closed-back headphones and 55 answer sheets (see Appendix C) on which to register their responses. Sound samples were presented to participants over headphones, directly connected to their computers. Participants played all audio files through Media Player Classic v6.4.9.

Participants were presented with a total of 55 listening trials. The first trial was repeated in trial 27. The first trial was included to familiarize participants with testing procedures (i.e., listening and response procedures). It was not included in any reported results. The next 54 trials constituted the actual test.

In each trial, participants listened to 5 audio samples, side-by-side. Samples included recordings at 5 kHz, 6 kHz, 7 kHz, 8 kHz and 10 kHz bandwidth. The order in which participants heard samples was randomized for each trial, and each sample was simply labeled with a letter, “A” through “E”. Therefore, listeners had no knowledge of individual bandwidths for any given set of samples. After listening to all of the samples in the trial, participants were asked to rate each sample using the provided answer sheets (see Appendix C for an example answer sheet). They were encouraged to play the list of audio cuts as many times as necessary to rate each sample. Their job was to rank-order all samples with **unique scores**, even if they found the quality of the samples to be very similar or identical[4]. For fine discrimination, participants were encouraged to rate each sample on a 50-point scale, anchored at increments of 10. This followed the ACR-MOS scale with the exception that participants were able to rate the samples as "failed" (0). Therefore, participants were advised to assign a number to each sample between 0 and 50; 0 = "failure", 10 = "bad", 20 = "poor", 30 = "fair", 40 = "good", and 50 = "excellent".

No recommendation was made concerning the sound cards to be used by participants, however it was required that all participants use the Sennheiser headphones that they received in the mailing. Participants were also encouraged to listen in a quiet listening space, free from both steady-state and temporal environmental noise. Participants were instructed to listen to half of the trials and take a 10-minute break. The total listening time for an experiment was approximately 2 hours. Participants were advised to refrain from taking the test if they were tired, cranky, had a head cold or severe allergies (or any other condition that would interfere with their ability to hear small differences in audio quality), or had too little time to complete the test in one sitting.

Three listening conditions were included: (a) a clean or unimpaired RF signal, (b) an impaired signal recorded at +6 dB D/U with first-adjacent channel interference, and (c) an impaired signal recorded at +15 dB D/U with first-adjacent channel interference. Unimpaired samples were included to provide listeners with the best opportunity to critically judge the audio quality. At the same time, +6 dB and +15 dB D/U signals were included so that experts could evaluate transmissions recorded in real-world, impaired conditions.

Two receivers were used, the JVC KS-FX490 car in-dash cassette (representing the median-bandwidth receiver), and the Panasonic CQ-CB9900U in-dash CD/HD Radio (representing the 80th percentile bandwidth receiver). Proposed receivers were selected based on objective measurements obtained in NPR objective testing. (See the following section, "Audio Measurements of AM Consumer Receivers" for a discussion of the selection criteria.)

Samples included male speech, female speech, male commercial, female commercial, rock, pop, country, classical and sportscast. Participants returned the answer sheets to Ellyn Sheffield, who supervised the entry of all data.

2.3.2 Participants

Thirty-six industry experts were sent packages. Twenty-one returned their answer sheets, but three had completed 27 or less of the 54 trials, so their data was eliminated from analysis. Of the 18 participants, 16 were male and 2 were female. Since most of the participants were homogeneous in age and predominantly male, preliminary analyses were not conducted on the data.

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[4] While most participants followed these directions, some respondents gave samples the same score on various trials. Although this practice did not follow the procedure, the answers were left in tact for data analysis.

2.3.3 Results

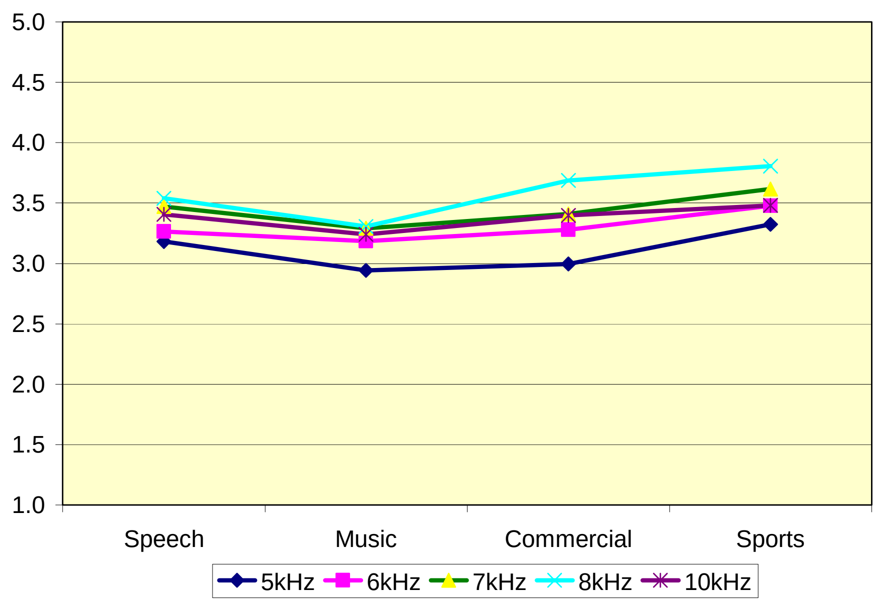
Due to errors in a few audio CD files, a small amount of data was not collected at 8 kHz on the Panasonic receiver (for a table of all results broken down by receiver and sound sample, see Appendix D).

Figure 1 through Figure 3 show the combined results from both receivers. Results indicate that, in general, participants reported hearing small differences between samples, although differences were more significantly pronounced in the speech genre in impaired conditions.

As shown in Figure 1, in unimpaired signal conditions, listeners generally preferred higher bandwidths to lower bandwidths; however this effect was not simply linear in that they regularly preferred 8 kHz to 10 kHz.

Figure 1: Unimpaired Signal Condition (JVC & Panasonic)

ACR-MOS Scale (1 = bad; 2 = poor; 3 = fair; 4 = good; 5 = excellent)



As shown in Figure 2 in the +15 dB condition, listeners generally preferred lower bandwidths to higher bandwidths, although, with the exception of speech, these differences were very small. In speech, they again showed a preference for lower bandwidths, particularly 7 kHz.

As shown in Figure 3 in the +6 dB condition, listeners generally preferred lower bandwidths (5, 6 and 7 kHz) to higher bandwidths (8 and 10 kHz) and in speech conditions they demonstrated a strong preference for 5 and 6 kHz.

Figure 2: +15 dB D/U Condition (JVC and Panasonic)

ACR-MOS Scale (1 = bad; 2 = poor; 3 = fair; 4 = good; 5 = excellent)

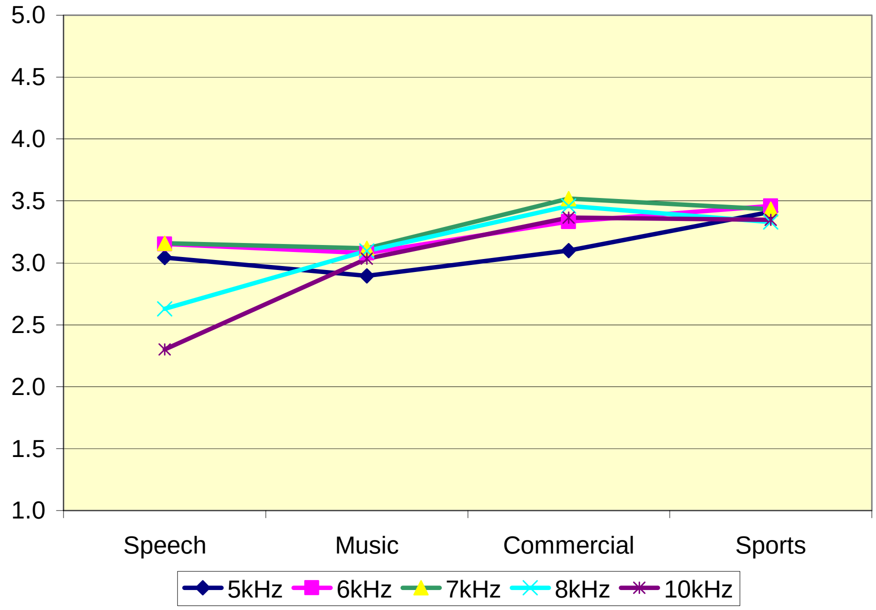
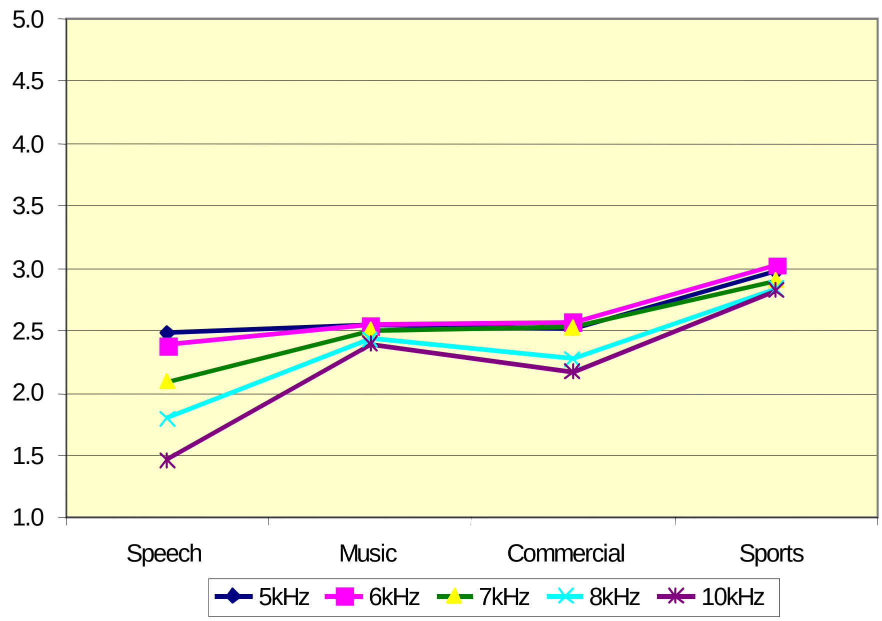


Figure 3: +6 dB D/U Condition (JVC and Panasonic)

ACR-MOS Scale (1 = bad; 2 = poor; 3 = fair; 4 = good; 5 = excellent)



Given these results, a recommendation was made to include 7 kHz bandwidth as the 3rd bandwidth for consumer testing. This recommendation was based on two conclusions:

- In unimpaired and +15 dB conditions, 7 kHz (and 8 kHz) seemed to be favored, even over 10 kHz in many cases.

- In the +6 dB condition, 7 kHz seemed most “different” from 10 and 5 kHz, thereby giving consumers a viable alternative to both extremes during consumer testing.

2.4 Consumer Test

2.4.1 Equipment and environment

Consumers were tested at Salisbury University, located in Salisbury, Maryland. Salisbury is a small city surrounded by suburbs and rural environment, located approximately 2 hours from Baltimore and Washington. The consumer test lasted approximately 2 hours, which included training on the equipment, and short breaks. Consumers were tested individually, in a large 35’ x 42’ room, used primarily for choral rehearsals at Salisbury University. The room environment was quiet, and remained free from all outside noise intrusion during testing sessions. Heavy drapes were drawn at the far ends of either side of the room to reduce the room’s reverberation time. The loudspeaker was placed on a stand near the middle of the draped wall. An area carpet that covered the tile floor was placed between the loudspeaker and the listening position.

Consumers were seated approximately 5 feet from the loudspeaker (a Genelec field monitor). A computer monitor was positioned between the loudspeaker and the listening position. The top of the monitor was positioned several inches below the bottom of the loudspeaker; therefore it in no way interfered with the listening experience.

An experimenter showed listeners how to register their responses through software especially designed to collect consumer response data. Listeners were given the opportunity to adjust the playback volume during the first practice trial, and this level was maintained throughout the remainder of the experiment. They controlled playback of the audio samples but were not allowed to register their responses until each sample of the sample pair was played entirely.

2.5 Methodology

Based on results from the Broadcast-industry test, consumers were tested on three transmission bandwidths: 5kHz, 7kHz and 10kHz. Because there were only small differences in audio quality among bandwidths in +15dB and unimpaired conditions (unimpaired was a proxy for +30dB), it was critical to select a subjective methodology that would enhance listeners’ abilities to discern differences when and where they occurred. A suitable method that reliability identifies small differences between samples is the A/B pair-wise comparison. In A/B testing, listeners are provided with two samples. After listening to both samples back-to-back, they can immediately register their response. Their judgment, therefore, does not rely on perceptual memory or an internal reference, as they have heard both samples within a relatively short time period. A/B methodology is easy to administer, the task is simple for listeners to master, and therefore it is considered an excellent methodology for discerning small differences in consumer (i.e., not expert) testing.

Consumers heard seven different samples, including female and male speech, voice-over (commercial), a sportscast, and rock, country and classical music. Over the course of the entire test, they listened to 189 sample pairs. After listening to 63 sample pairs, consumers were given a break, and they were given another break after listening to 63 more sample pairs. After listening to each sample pair consumers were asked to judge which sample they thought had better quality, how big the difference was and whether they would continue to listen to the radio, given the quality of the samples. Because consumers were given a "forced-choice" question (i.e., which sample they liked, "A" or "B"), and because differences were reasonably small, consumers were told that they would occasionally come across samples that sounded quite similar, perhaps even equal in quality. They were instructed to "do their best", picking the one they felt was slightly better and that in question 2, they would have the opportunity to report that the difference was negligible or non-existent. The complete Experimenter script is described in Appendix E. For each radio at each D/U ratio, all combinations of comparisons were included: 5 kHz vs. 7 kHz; 5 kHz vs. 10 kHz; and 7 kHz vs. 10 kHz.

2.5.1 Participants

Forty-four listeners (23 males and 21 females) were recruited for the consumer test, distributed between 19 and 71 years of age. Data from 40 qualified listeners was collected, where qualification was based on a post-hoc screening test designed to eliminate outliers. Two listeners were eliminated because they failed to complete the listening test. An additional listener was eliminated because he did not reach criterion on the post-hoc screening analysis. A final listener was eliminated in order to make even the number of responses from each gender. Table 2 shows the demographic breakdown of listeners. Listeners were recruited from several sources, including a general e-mail posting to students, faculty and members of the Salisbury University community, and flyers posted in Salisbury and the surrounding areas.

Table 2 – Distribution of Listeners

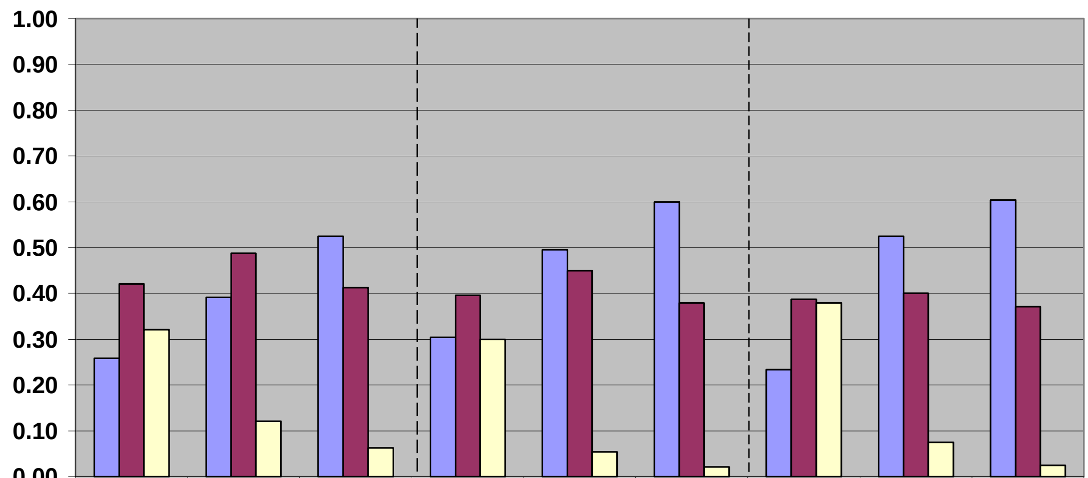
Age (years)	**Male**	**Female**
18-29	5	6
30-39	5	4
40-49	5	4
50+	5	6

2.5.2 Results: Bandwidth Preference

Figure 4 through Figure 7 show listener preference, divided by genre. For the purpose of analysis and presentation, individual cuts were grouped together in 4 genres: speech, music, commercials and sportscast. For a complete table of results, see Appendix F. Each figure shows the percentage of participants who picked one bandwidth over another (e.g., 5 kHz over 10 kHz) at various D/U signal conditions by receiver. Because this was a forced choice test (i.e., participants were asked to choose which sample, "A" or "B" had better quality) and there were three combinations of forced-choice pairs (i.e., 5 kHz vs. 7 kHz; 7 kHz vs. 10 kHz; 5 kHz vs. 10 kHz), 33% represents the level of responses that would be considered "at chance". As a rule of thumb, any positive or negative difference from 33% of 12 percentage points (i.e., 45% or 21%) should be considered significantly different from chance. Thus, finding that 21% or 45% of respondents preferred a particular bandwidth in an individual condition should be considered significant.

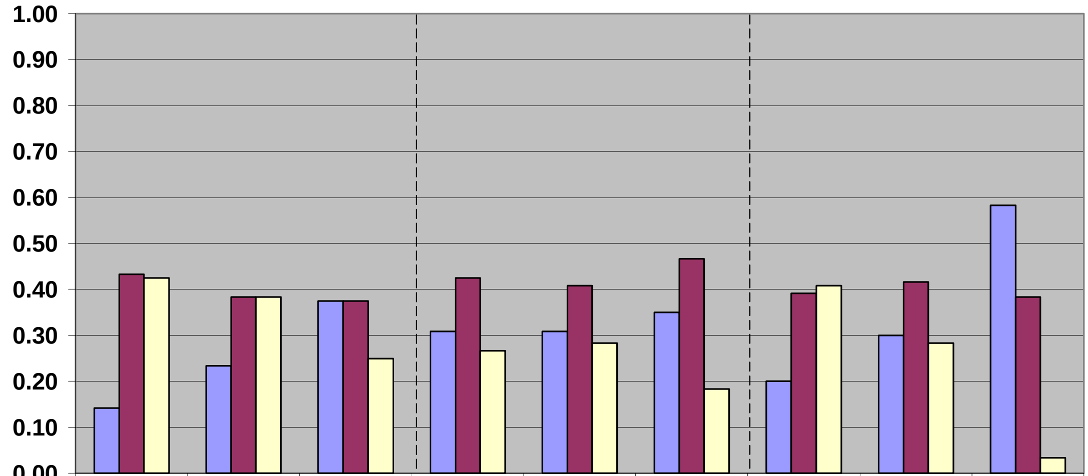
Notice that the findings for "speech" follow a significantly different pattern than findings for all other genres. Participants clearly favored 5 kHz and 7 kHz in speech, while in music and commercials (except for 6dB in the median and 80% receiver conditions) preferences were not clearly articulated. In sportscast, participants demonstrated a slight preference for higher bandwidths.

Figure 4: Speech Results for Three Receiver Bandwidths (20%, Median, and 80%)



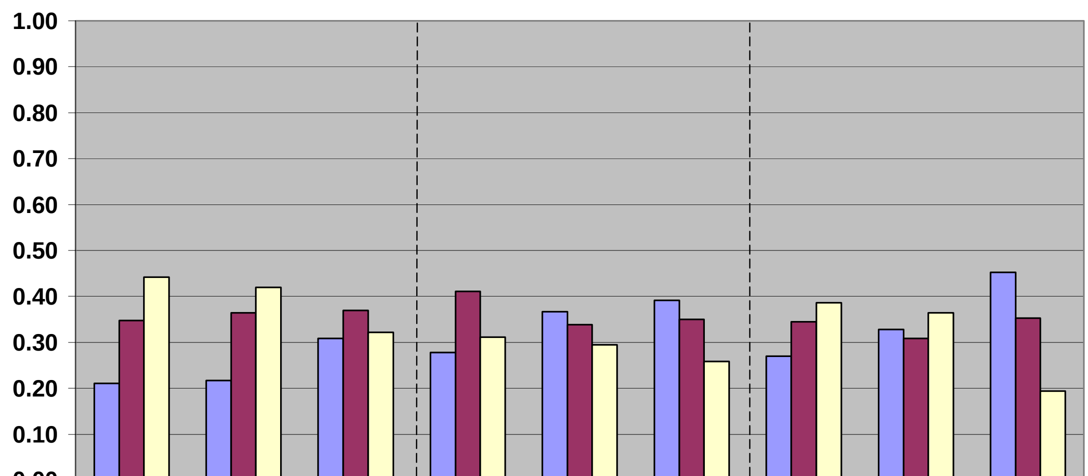
	30dB	15dB	6dB	30dB	15dB	6dB	30dB	15dB	6dB
		20%			Median			80%	
5kHz	0.26	0.39	0.53	0.30	0.50	0.60	0.23	0.53	0.60
7kHz	0.42	0.49	0.41	0.40	0.45	0.38	0.39	0.40	0.37
10kHz	0.32	0.12	0.06	0.30	0.05	0.02	0.38	0.08	0.03

Figure 5: Commercial Results for Three Receiver Bandwidths (20%, Median, and 80%)



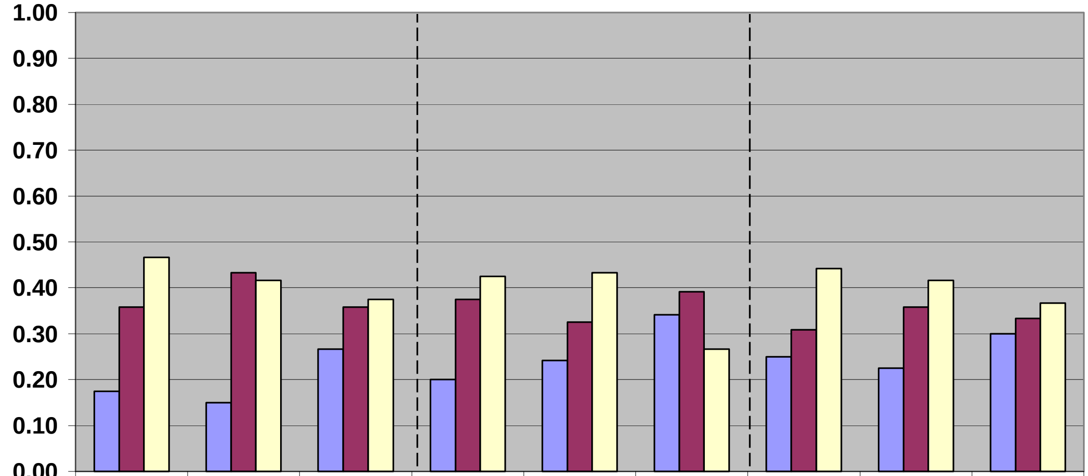
	30dB	15dB	6dB	30dB	15dB	6dB	30dB	15dB	6dB
		20%			Median			80%	
5kHz	0.14	0.23	0.38	0.31	0.31	0.35	0.20	0.30	0.58
7kHz	0.43	0.38	0.38	0.43	0.41	0.47	0.39	0.42	0.38
10kHz	0.43	0.38	0.25	0.27	0.28	0.18	0.41	0.28	0.03

Figure 6: Music Results for Three Receiver Bandwidths (20%, Median, and 80%)



	30dB	15dB	6dB	30dB	15dB	6dB	30dB	15dB	6dB
		20%			Median			80%	
5kHz	0.21	0.22	0.31	0.28	0.37	0.39	0.27	0.33	0.45
7kHz	0.35	0.36	0.37	0.41	0.34	0.35	0.34	0.31	0.35
10kHz	0.44	0.42	0.32	0.31	0.29	0.26	0.39	0.36	0.19

Figure 7: Sports Results for Three Receiver Bandwidths (20%, Median, and 80%)



	20%			Median			80%		
	30dB	15dB	6dB	30dB	15dB	6dB	30dB	15dB	6dB
5kHz	0.18	0.15	0.27	0.20	0.24	0.34	0.25	0.23	0.30
7kHz	0.36	0.43	0.36	0.38	0.33	0.39	0.31	0.36	0.33
10kHz	0.47	0.42	0.38	0.43	0.43	0.27	0.44	0.42	0.37

2.5.3 Results: Magnitude of Preferences

Because Broadcast-industry experts indicated that differences in audio quality between bandwidths were reasonably small in a majority of cases, we felt that it was particularly important to characterize the magnitude of consumer responses. Consumers were asked in two ways to qualify their responses: (a) to indicate how large the difference was between the two samples; and (b) to suggest where they might turn the radio off instead of continuing to listen to the broadcast. Obviously the latter question, often referred to as a “threshold” question, is an extreme measurement of dissatisfaction, and must be interpreted very carefully. It is widely accepted that motivation interacts heavily with a consumer’s decision to turn off a radio program. That is, if a consumer is invested heavily in the content of a radio program, s/he will be far less likely to turn off the program, regardless of audio quality. Thus, the best way to interpret this data is to focus on the relative differences in bandwidths, not the absolute turn off rates.

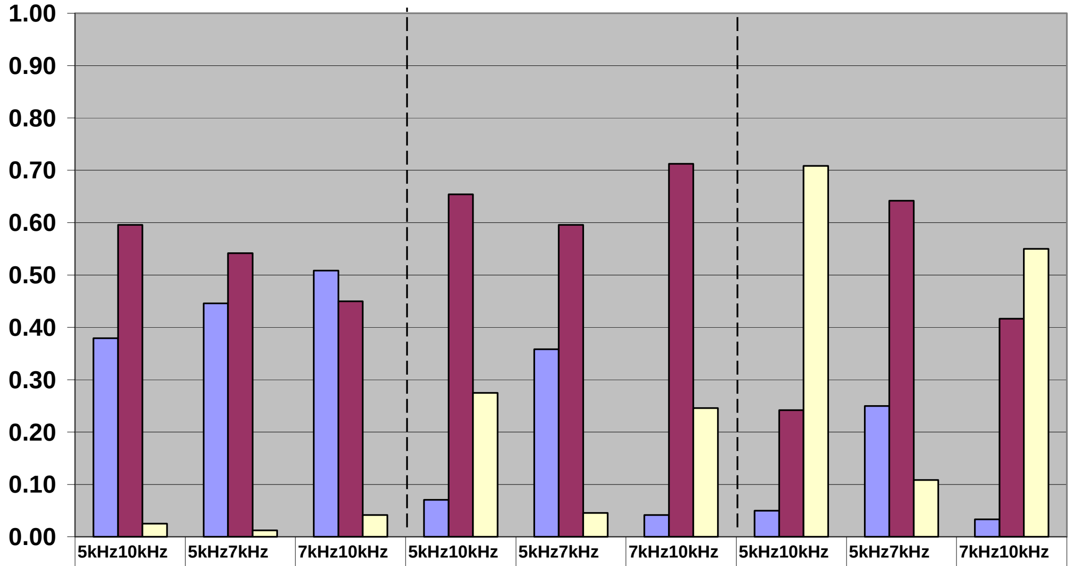
Figure 8 through Figure 11 show how large a difference they felt they heard between the two samples. Answers ranged from “I didn’t hear a difference, you made me pick” to “I heard an extreme difference”. For the purpose of analysis and presentation, 5 response categories were collapsed into 3 categories (as shown in Table 3) and receivers were collapsed. For complete data, see Appendix F.

Table 3 – Categories collapsed for analysis

Original category	Collapsed category
I didn't hear a difference, you made me pick	No difference
The difference was noticeable but very small	Difference
The difference was somewhat noticeable	Difference
The difference was noticeable	Big difference
The difference was very noticeable	Big difference

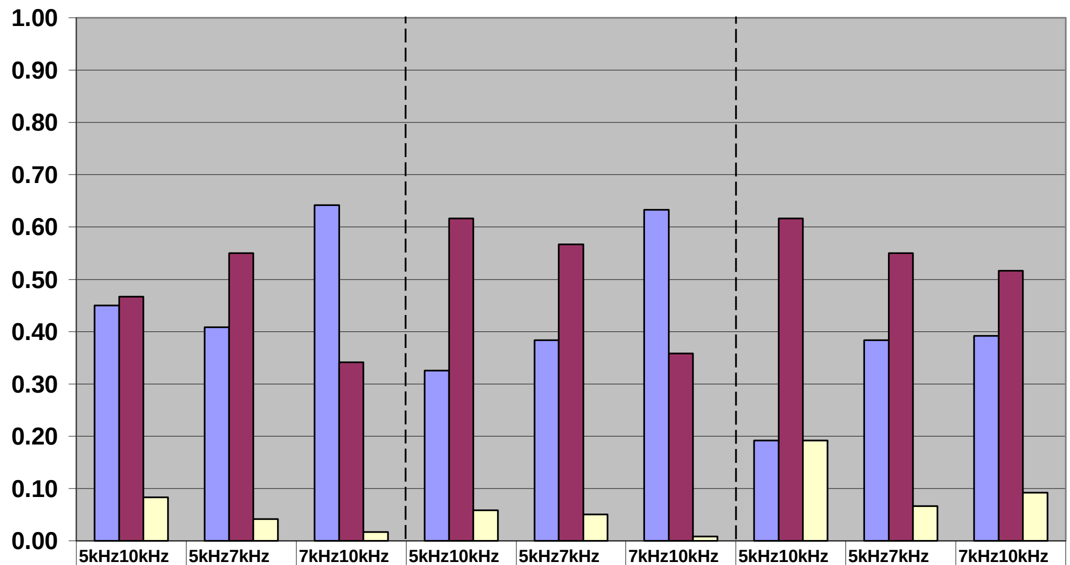
Notice that, as with preference responses, speech followed a significantly different pattern than all other genres. Consumers reported hearing much larger differences in speech, particularly in the +6 dB noise conditions. This is not surprising given the density profile of speech versus music, sports and commercials, and the extreme level of impairments found at +6 dB. Nevertheless, because participants reported hearing the biggest differences in the noisiest condition (+6 dB), we may infer that they are most often equating the concept of "difference" with noise on the sample (in this case 1st adjacent channel noise). These data, taken together with preference data suggests that the single most important criteria consumers use when judging AM transmission audio quality (in this case preferring one bandwidth over another) is the amount of interference noise they hear on the sample, and not necessarily fidelity.

Figure 8: Differences heard in speech for Three Impairment Levels (30dB, 15dB and 6dB)



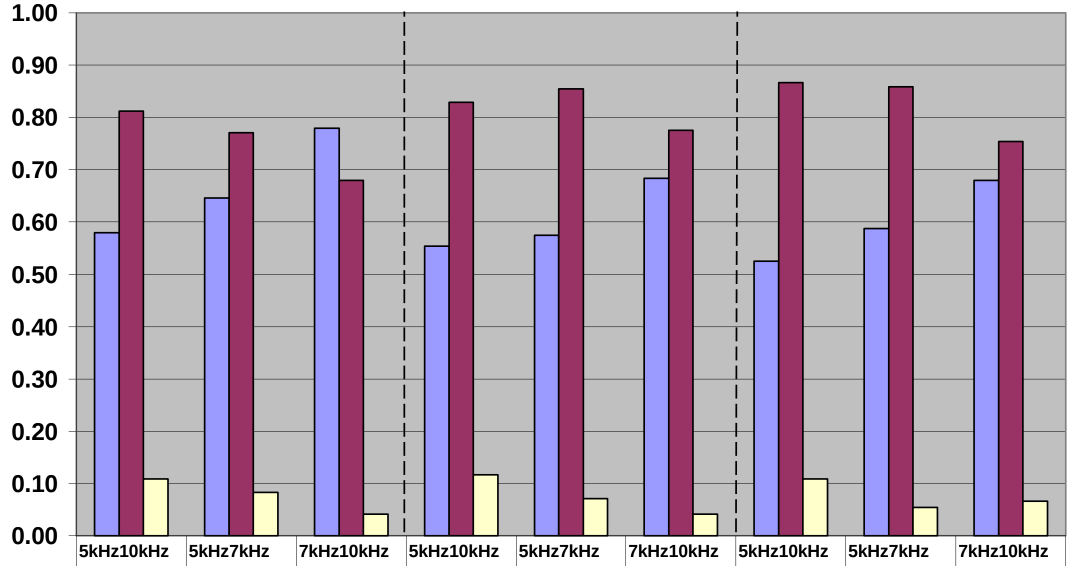
	30dB			15dB			6dB		
	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz
No difference	0.38	0.45	0.51	0.07	0.36	0.04	0.05	0.25	0.03
Difference	0.60	0.54	0.45	0.65	0.60	0.71	0.24	0.64	0.42
Big difference	0.03	0.01	0.04	0.28	0.05	0.25	0.71	0.11	0.55

Figure 9: Differences heard in commercials for Three Impairment Levels (30dB, 15dB and 6dB)



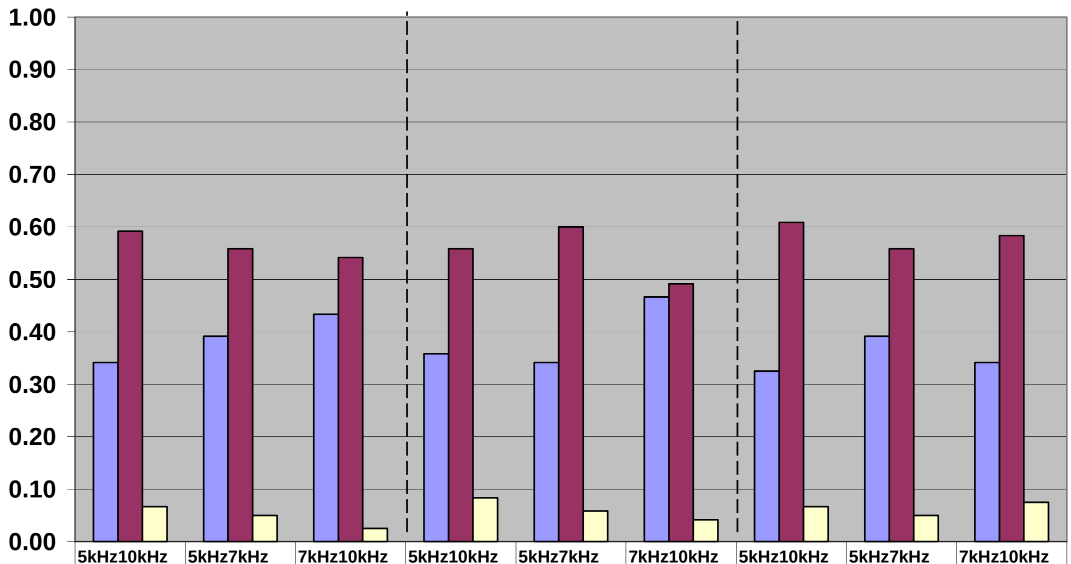
	30dB			15dB			6dB		
	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz
No difference	0.45	0.41	0.64	0.33	0.38	0.63	0.19	0.38	0.39
Difference	0.47	0.55	0.34	0.62	0.57	0.36	0.62	0.55	0.52
Big difference	0.08	0.04	0.02	0.06	0.05	0.01	0.19	0.07	0.09

Figure 10: Differences heard in music for Three Impairment Levels (30dB, 15dB and 6dB)



	30dB			15dB			6dB		
	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz
No difference	0.58	0.65	0.78	0.55	0.58	0.68	0.53	0.59	0.68
Difference	0.81	0.77	0.68	0.83	0.85	0.78	0.87	0.86	0.75
Big difference	0.11	0.08	0.04	0.12	0.07	0.04	0.11	0.05	0.07

Figure 11: Differences heard in sports for Three Impairment Levels (30dB, 15dB and 6dB)



	30dB			15dB			6dB		
	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz	5kHz10kHz	5kHz7kHz	7kHz10kHz
No difference	0.34	0.39	0.43	0.36	0.34	0.47	0.33	0.39	0.34
Difference	0.59	0.56	0.54	0.56	0.60	0.49	0.61	0.56	0.58
Big difference	0.07	0.05	0.03	0.08	0.06	0.04	0.07	0.05	0.08

Figure 12 through Figure 15 show how often consumers would listen to samples or turn them off, divided by genre. Taken as a group, the number of transmissions consumers would keep listening to comprises approximately 65% of the listening samples, compared to 35% of the samples that they would turn off. This suggests that, in general, consumers found the audio quality acceptable, particularly in +30 and +15 dB conditions. However, this also indicates that there was a fairly high percentage of "turn-offs". As expected, the number of "turn offs" increased as the D/U ratio got worse. At +30 dB, the number of turn-offs was 507 (accounting for 19%), whereas at +15 dB, the number increased to 813 (accounting for 31%) and at +6 dB, the number again increased to 813 (or 50%) These results were particularly pronounced in the 20% and 80% receiver.

As shown in, in speech the number of turn-offs rises as the noise conditions worsen. This pattern (as shown in Figure 13 through Figure 15) does not hold for the other genres. These results dovetail with both preference ratings and size of perceived impairments.

Figure 12: "Would you continue to listen (Speech)?" for Three Receiver Bandwidths

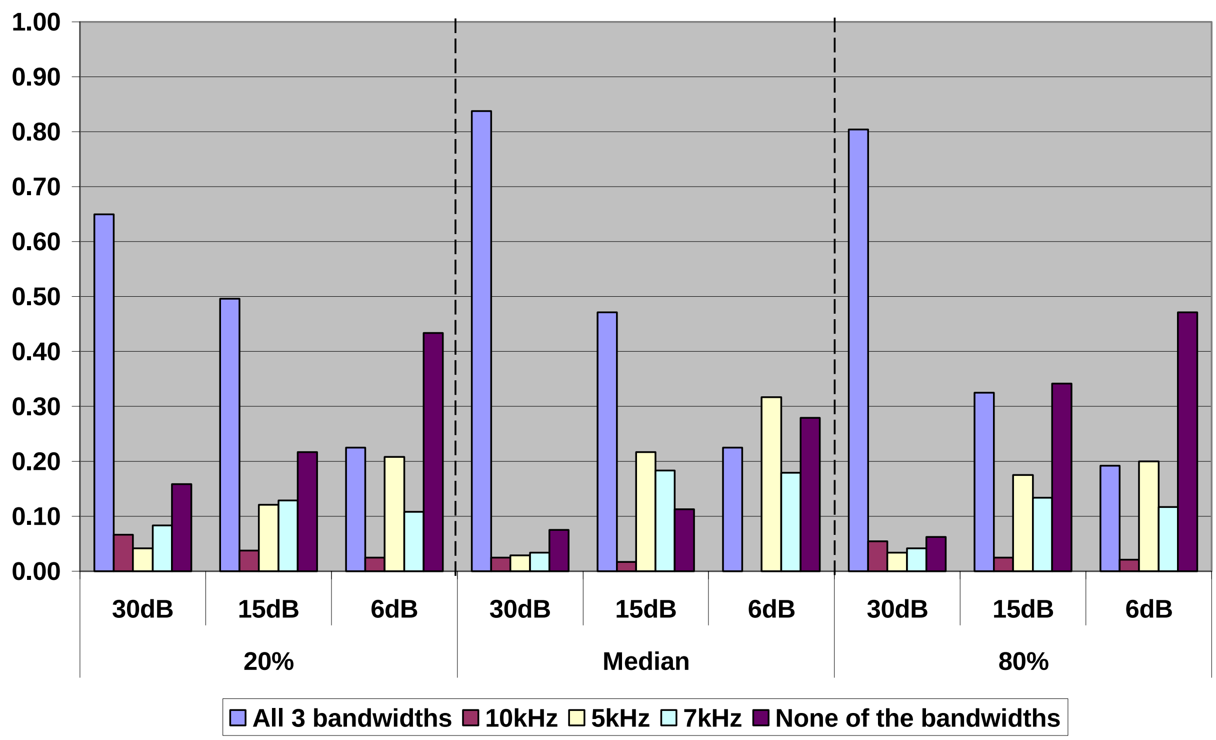


Figure 13: "Would you continue to listen (Commercial)? " for Three Receiver Bandwidths

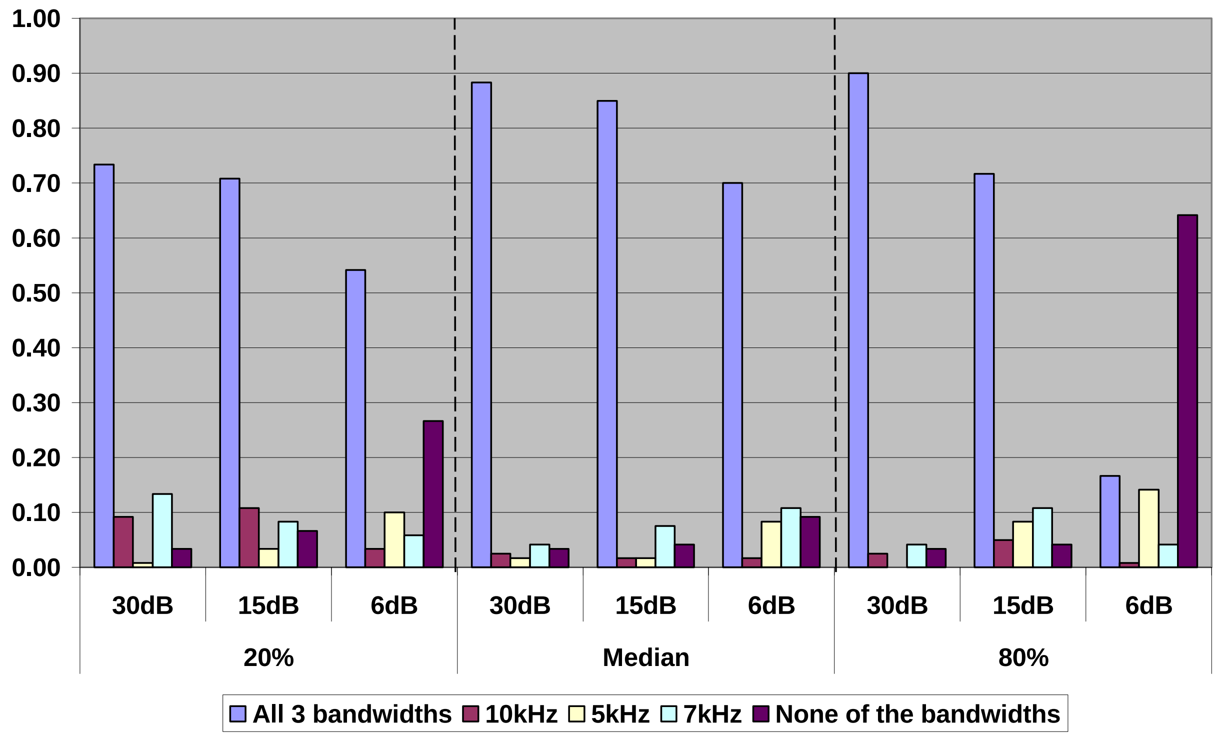


Figure 14: "Would you continue to listen (Music)? " for Three Receiver Bandwidths

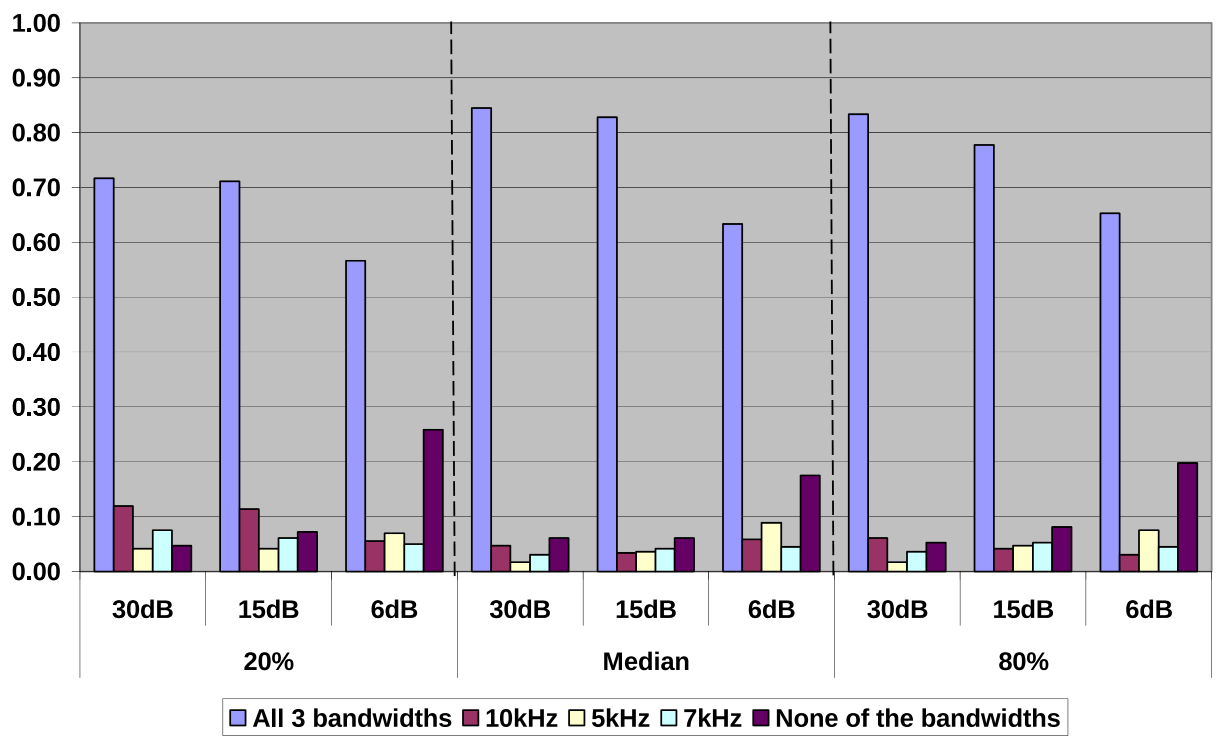


Figure 15: "Would you continue to listen (Sports)? " for Three Receiver Bandwidths

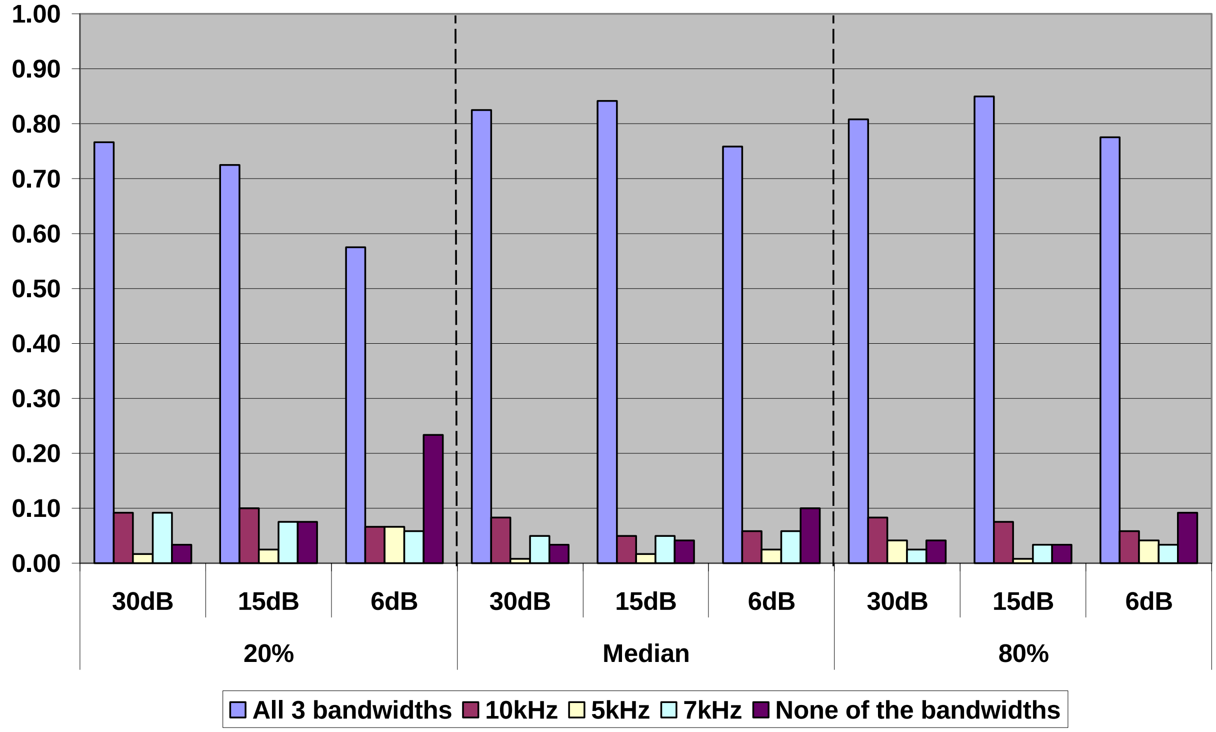


Figure 10 shows a further breakdown of the data by genre, focusing on the incidents of consumers reporting they would keep listening to one sample but turn the other off (i.e., I'd listen to "A", not "B"). The number of responses at a particular kHz level is a compilation of all trial-pairs which include that kHz level and all other kHz samples with which they were paired. For example, at 5 kHz in Music, consumers reported 13 times that they would continue to listen to 5 kHz but they would turn off the other sample (which could be 7 or 10 kHz). When interpreting this table, remember that reports of "I'd listen to "A" and not "B" represent a reasonably small percentage of consumer reports. Notice that consumers reported they would keep listening to 5 kHz significantly most often in speech.

2.6 Conclusions

Results from both Broadcast-industry and consumer testing suggest the following:

- The perceived difference in audio quality between 5 and 10 kHz is reasonably small, except when participants are listening to speech. In fact, there is little indication that consumers hear any difference between 7 and 10 kHz when they are listening to music, commercials and sportscasts, regardless of D/U ratios (the rare exceptions indicate people prefer 7 kHz to 10 kHz)
- In unimpaired or relatively unimpaired (+30 dB D/U) conditions, people tend to prefer higher bandwidths to lower bandwidths. However, as indicated in

broadcast-industry testing, their preference is for 8 kHz, and as indicated in consumer testing, they have no preference between 7 kHz and 10 kHz.[5]

- In speech, consumers prefer lower bandwidths (5and 7 kHz) to higher bandwidths. In +15 dB and +6 dB D/U conditions this preference is overwhelmingly demonstrated.
- The magnitude of consumer's preference varies as a function of D/U ratio and type of audio. In harsher noise conditions, people claim that they hear larger differences. Additionally, in speech conditions, people claim that they hear larger differences than in music, sportscast or commercials.
- The data suggest that the rather substantial "turn-off" rate (resulting largely from data in the +6 dB condition) can be ameliorated by switching to a lower transmission bandwidth.
- The specific preferred bandwidth varies as a function of genre and dB D/U level, but appears to reside between 5 and 7 kHz.

[5] Listener preference for 8 kHz, or equal preference of 7 vs. 10 kHz, is surprisingly contrary to expectation. One reason for this may be that high frequency components of the audio signal create intermodulation products within the audio pass band of the receiver, which add audible distortion. These high frequency components are above the pass band of most receivers and contribute little to the audible fidelity of the received signal.

3 Audio Measurements of AM Consumer Receivers

3.1 Introduction

This section of the report documents audio performance measurements of AM broadcast reception with 30 current consumer receivers. The study was performed on behalf of the AM Study Task Group of the National Radio Systems Committee with support from the Consumer Electronics Association and the National Association of Broadcasters. All tests were performed in NPR Labs at the headquarters of National Public Radio in Washington, DC.

The receiver study was designed to collect data in two areas:

- Baseline audio performance of the sample radios, including frequency response, harmonic distortion, intermodulation distortion and signal to noise ratio;

- Objective noise level differences with different audio transmission bandwidths, relative to the current 10 kHz standard. The study compared 5, 6 and 7 kHz. Weighted Quasi-Peak (WQP) noise levels were measured with a psophometer, which approximates the response of human hearing to audible noise. The first-adjacent (±10 kHz) channel interfering signal was modulated with a pulsed frequency-shaped noise designed to resemble the dynamic and spectral characteristics of program audio.

The study measured a large sampling of receivers that are representative of current consumer sets in the following areas:

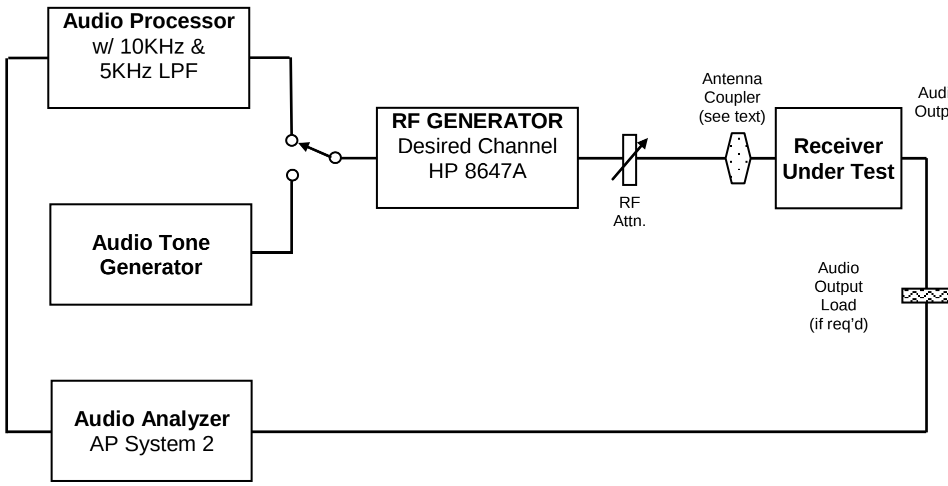
- Home stereo receivers
- Shelf/mini systems
- Portable and CD boom box sets
- After-market car radios, including CD and cassette models
- Original equipment car radios
- Clock radios
- HD Radio receivers (in this study, after-market car radios).

The full list of tested receivers, grouped by category, is included in Appendix J. This table summarizes key audio performance measurements and identifies the three receivers used to prepare the audio samples for consumer subjective testing. Detailed measurements on each receiver are included in Appendix K.

3.2 Methodology

Testing was performed according to the detailed test procedure in Appendix L. Baseline audio performance was measured with the Test Bed setup in Figure 16. The Audio Precision System 2 provided the audio test signals and performed automated audio measurements. An Orban model 9200 Digital Audio Processor provided the modified 75 µS pre-emphasis and 10 kHz low-pass filtering per the NRSC-1 standard before modulation by a Hewlett-Packard model 8647A generator.

Figure 16 - Test Bed setup for audio performance measurements



Receivers that use a separate external antenna, such as car radios, were tested with direct connections to their antenna inputs. Some receivers, such as home stereos and shelf systems, are supplied with an external "loop" antenna. The remainder, including portables and table radios, has an internal ferrite rod antenna. These radios were tested by magnetic RF induction from the shielded loop shown in Figure 20. To avoid extraneous noise and signal interference these radios were measured inside a shielded test cabinet and RF signal, power and audio were brought through bulkhead connectors.

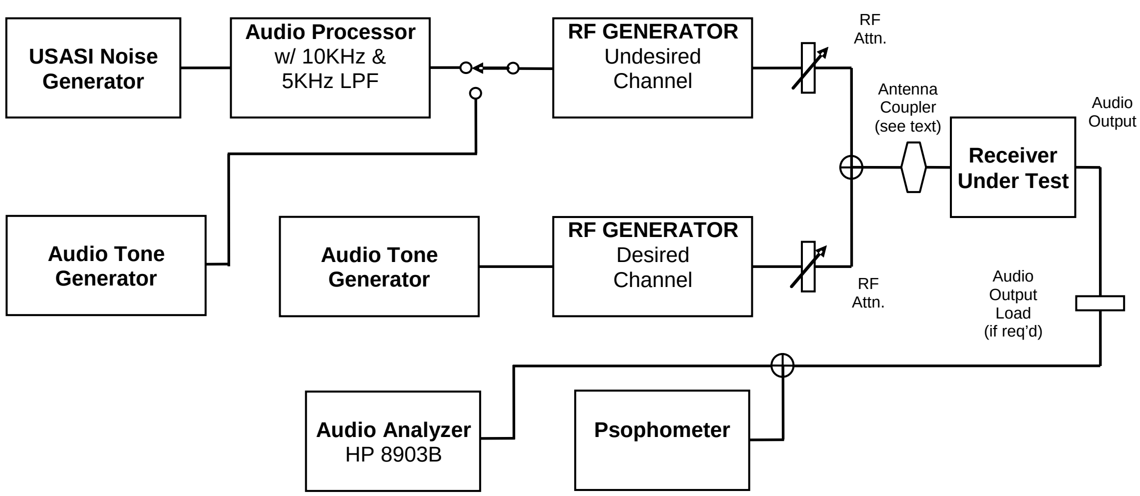
The AM receiver audio frequency response graphs in Appendix K were made with the NRSC-1 pre-emphasis curve in the transmission chain, representing the proper "end to end" performance of the receivers. The frequency sweeps were conducted 10 dB below 70% modulation at 1 kHz, so that pre-emphasis resulted in a maximum modulation of no more than 70% at the highest audio frequencies. All of the graphs show 50-10,000 Hz in a logarithmic frequency scale, with a 0 dB reference at 1 kHz.

The receiver reports in Appendix K include measurements of two types of intermodulation distortion and noise. These graphs show the frequency spectrum from 50 Hz to 10 kHz using a Fast Fourier Transform with Blackman-Harris windowing. The first of this pair of graphs depicts 400 and 700 Hz at equal amplitude and 70 percent total modulation. The amplitude of the graph is normalized so that the top of the graph represents 70% reference modulation and 700 Hz is displayed at its modulation level of -9.1 dB [20*log (0.7/2)].

The second graph depicts a combination of 10 sinusoidal signals of equal amplitude, distributed logarithmically and non-harmonically in frequency from approximately 50 Hz to 10 kHz: 52.7, 87.5, 163, 294, 526, 950, 1716, 3099, 5595, and 10,002 Hz. Amplitude of each tone was the inverse of the NRSC-1 modified 75µS curve. When the audio signal was passed through the audio processor the signal was pre-emphasized, resulting in equal modulation amplitude from each tone. However the 10,002 Hz tone was suppressed so much by lowpass filtering that it effectively contributed nothing to total modulation and was usually undetectable. Thus, the graph for each receiver is labeled as a “multi-tone” test rather than a 10-tone test. The instantaneous sum of the remaining nine sinusoids was set to a peak modulation of 70 percent and the amplitude scaling is normalized so the 950 Hz tone is registered at -22.2 dB [20*log (0.7/9)]. While multi-tone testing is unusual, this complex signal may resemble actual program material better than simple tone tests. The graphs were prepared in Excel from the original measurement data, which is available for further analysis. Differences in noise floor between 2-tone and multi-tone tests in some receivers is due to changes in RF signal coupling between the H-field loop and the receiver’s antenna loop.

Objective measurements were performed on each receiver to determine the levels of audible noise resulting from interference on first-adjacent channels (±10 kHz) with audio transmission bandwidths of 5, 6, and 7 kHz, with the current 10 kHz limit. A Hewlett Packard 8903B audio analyzer (with internal psophometer) was used, which combines a rising frequency response across the audio band to a peak at 6.1 kHz with a quasi-peak reading voltmeter. Aside for test tones for lineup, the Desired Channel generator was quiet. Modulation of the first-adjacent (±10 kHz) channel interfering signal was a frequency-shaped pulsed noise standardized by USASI (now ANSI). The noise was processed through a broadcast multi-band compressor limiter.

Figure 17 - Test Bed diagram for RF interference measurements



Measurements are listed in Appendix K for each receiver, titled Psophometer-Based Adjacent-Channel Interference. Each table reports the audio noise level, referenced to 1 kHz at 70 percent modulation, for interference at RF Desired-to-Undesired ratios of 30 dB, 15 dB, 6 dB (the minimum for FCC allocation purposes) and 0 dB.

3.3 Discussion of Results

It is apparent from a review of the individual receiver graphs that with only a few exceptions, frequency response falls off above 1 or 2 kHz, although there are wide differences in slope. Wide variation among the tested receivers made the choice of a "dB down" reference point for bandwidth comparison more difficult. For example, the 1995 Chevrolet Camaro radio has a -3 dB frequency of 3.7 kHz, while the 2002 Ford Mustang radio's -3 dB frequency is 3.2 kHz (both relative to 1 kHz). However the cutoff slope of the Mustang radio is less steep than the Camaro radio, making the -3 dB point less representative of the audible frequency cutoff in AM receivers. Thus, a frequency cutoff of -10 dB was chosen for comparison. For the -10 dB cutoff points, the Camaro audio bandwidth is 4.3 kHz and the Mustang's is 6.1 kHz. The choice of -10 dB reference was reinforced by receiver listening tests during measurement, in which -10 dB correlated better with audible bandwidth than other reference points.

Figure 18 - Frequency Response mean and standard deviation for all tested receivers

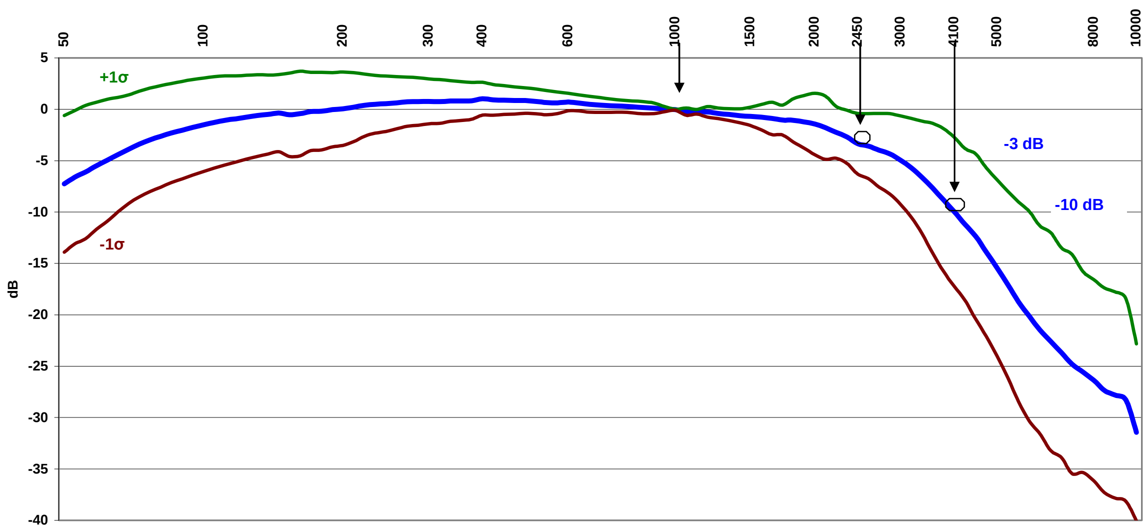


Figure 18 illustrates the combined frequency response of all receivers through the test bed (blue line), with the -3 dB point at 2450 Hz and the -10 dB point at 4100 Hz. The overall variation in audio bandwidths is shown by the standard deviation for the entire test population in green (σ+1) and brown (σ-1). For example, first-order standard deviation at the -10 dB point is approximately -2.6 dB and -17.2 dB, a range of 14.6 dB.

Table 4 - Summary of frequency response for all receiver groups

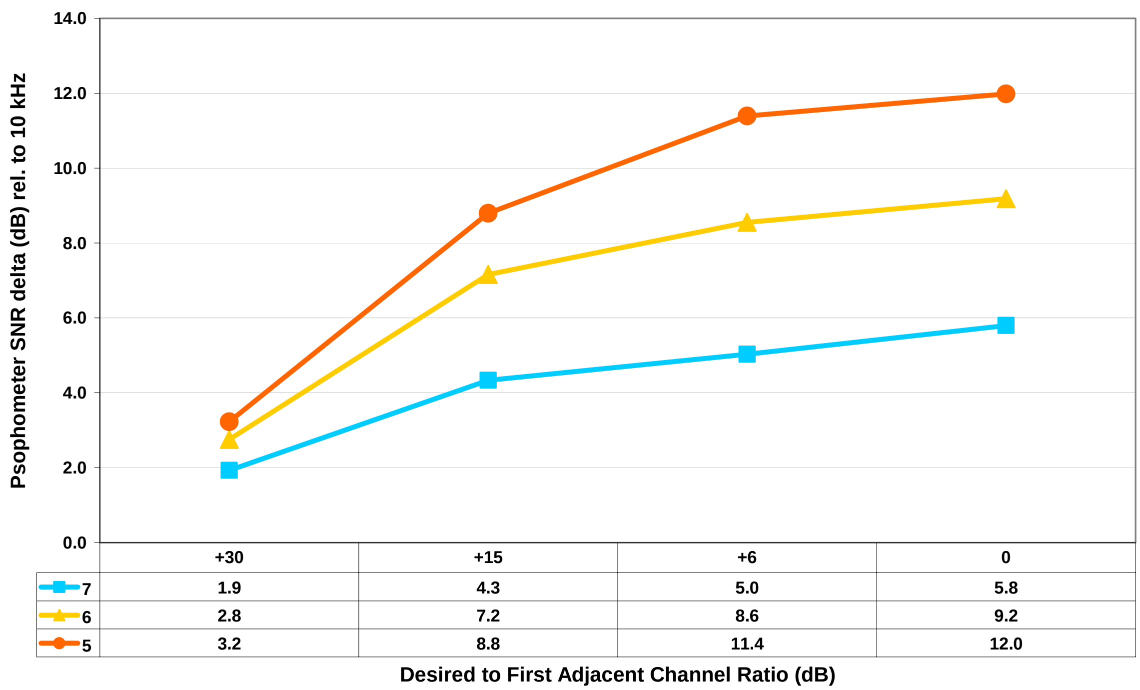
Receiver Category	**-3 dB Frequency (Hz)**	**-10 dB Frequency (Hz)**
Home Stereo	2325	3775
Shelf/mini systems	3175	4725
Portable/CD boom box	2631	4550
Clock	3250	5525
Car In-dash	2725	4175
HD Radio (car)	4000	4700
OEM car	3200	4580

Table 4 summarizes the mean -10 dB frequencies by receiver category. It is notable that the category of widest response is the clock radio, which is the group with lowest unit cost. This may be due to relatively low-cost designs having the fewest frequency-selective components that limit audio bandwidth, or to the use of filter devices with less "Q", or both. However home stereos exhibited the poorest audio bandwidth, despite the opportunity to use more sophisticated RF and IF filter designs. OEM car radios exhibit a noticeably wider bandwidth than the after-market car radios.

Some of the tested radios showed a rise in frequency response below 1 kHz, which combined with the narrow bandwidth to make these radios sound even more "boomy" and deficient in highs. All the radios exhibited an increasing rate of roll off with frequency, so that slopes above the -10 dB point became very steep. Consequently, within a fraction of an octave above the -10 dB frequency most receiver measurements are dominated by noise. Some receivers with high noise level, such as the Chevrolet Suburban OEM radio, were re-tested at a higher RF level in an attempt to measure higher frequency bandwidth.

In addition to basic signal to noise ratio under unimpaired transmission conditions, each receiver was evaluated for change in WQP (psophometer-based) signal to noise ratio with an adjacent channel interference (±10 kHz). Measurements were performed using three different audio transmission bandwidths and desired-to-undesired RF signal ratios of +30, +15, +6 and 0 dB. A table showing separate signal WQP to noise ratios for upper and lower channel interference is included with each receiver in Appendix K.

Figure 19 - SNR Changes with Adjacent Channel Interference for 5, 6 and 7 kHz Transmission Bandwidths Relative to 10 kHz



The upper and lower adjacent channel interference noise measurements of each receiver were averaged, and those receivers with WQP SNR measuring at least a 2 dB above their unimpaired (interference-free) noise floor were included in combined results.[6] The effect of transmission bandwidth on WQP SNR the combined group of receivers is summarized in Figure 19. It is apparent that transmission with a 5 kHz bandwidth at +6 dB D/U reduces interference noise by 11.4 dB compared to the 10 kHz (NRSC-1) reference. Differences with 6 and 7 kHz are 8.6 and 5.0 dB, respectively, at this D/U ratio. The *audible* differences at +30 dB D/U were actually larger than measured because the changes in interference noise at lower transmission bandwidths were obscured by the measured WQP noise level of receivers with high internal noise.

3.4 Audio and RF Connection Notes

All audio measurements were collected from the headphone jack, where available. This included most receivers in the test group except car radios and two table radios. The audio outputs of all car radios were measured at the Left Channel loudspeaker terminals with an 8-ohm non-inductive high-power resistor. Two of the receivers lacked headphone jacks, the Boston Acoustics Recepter and the Sima Weather Alert. For these sets, a calibrated Bruel & Kjaer instrumentation microphone was used to acoustically measure the audio performance. Figure 20 shows the acoustic setup inside a four-sided box made of closed-cell blocks approximately 1'x4'x4' to absorb stray reflections from floors, walls or ceilings that might disturb the frequency response measurements.

Figure 20 - Acoustic testing of Sima table radio with Bruel & Kjaer instrumentation microphone inside acoustic box of 1-ft. thick closed-cell foam. Magnetic field loop antenna also shown.

Figure 20 also shows the Scott & Associates LP-3 Standard H-Field Loop that was used to radiate RF signals to receivers with supplied antennas. These receivers employ either an internal ferrite rod antenna or an external wire loop antenna connected to the receiver's antenna terminals. In either case all measurements were made with the

[6] The wideband noise response of the psophometer and the high internal noise level of many radios obscured the changes at occurring 15 dB and 30 dB D/U ratios. To avoid substantially obscuring the noise differences at these higher D/U ratios four receivers having less than 2 dB WQP margin relative to unimpaired conditions were excluded from that combined data.

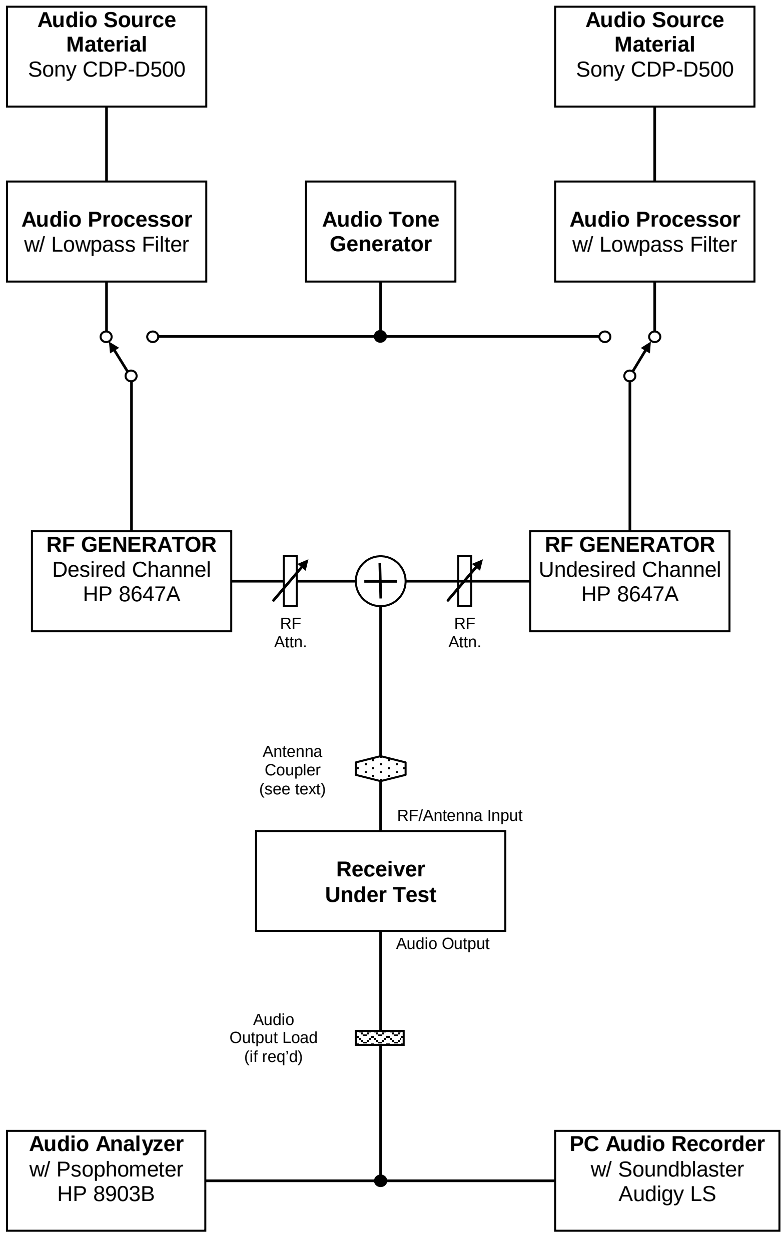
antenna (or entire receiver) inside a Ramsey Electronics STE-5000 shielded enclosure, providing at least 90 dB of isolation from electrostatic or electromagnetic fields in the lab environment. While most receivers exhibited internal noise levels that were greater than the environmental noise, the audio signal-to-noise ratio of some receivers benefited from antenna operation inside the shielded enclosure. The H-Field Loop was placed inside the enclosure and connected through a shielded bulkhead connector to the RF signal generator using double-shielded RG-58U cable. The audio line from the receiver to the test bed was made through a shielded bulkhead connector. For AC line-powered receivers operated inside the enclosure, the filtered feed-through coupling in the STE-5000 was used.

The placement and orientation of the antenna (or receiver cabinet) was tested with each receiver to determine the optimum signal coupling. Experimental measurements prior to testing showed that frequency response was not affected by operating the H-Field Loop and receivers inside the STE-5000 shielded enclosure, relative to operation in an open-air configuration. For receivers using H-Field Loop coupling the signal power levels reported herein are the RF output powers of the signal generator. Due to magnetic coupling losses the actual RF power transferred to the antenna circuits in receivers is substantially less than the listed values.

4 Acknowledgements

We would like to thank all the Broadcast-industry listeners for their participation in Phase 1 testing, and especially David Layer for recruiting so many well-qualified listeners. We would also like to thank Dean Timothy O'Rourke and Dr. Linda Cockey for sharing their facilities at Salisbury University. Special thanks to Shannon Lamoreaux, Ashley Sedorovich, Sarah Mitchell, Jonathan Lugo and Jennifer Stout for helping with testing and entering participant data, Sam Goldman, and Kyle Evans of NPR, and Matthew Burrough of RIT for developing the subjective testing software.

Appendix A - Recording Test Bed



AMSTG Pilot Listening Study
Guidelines for Participants

Hello!

Thank you very much for participating in the AMSTG pilot study. Your input is both necessary and much appreciated.

The following are guidelines that you should use during your listening session. **BEFORE STARTING THE TEST** please read these guidelines carefully. *If you have any questions, please direct them to Ellyn Sheffield, egsheffield@comcast.net, egsheffield@salisbury.edu, or call 410-726-7301 (my cell).*

FOR SHIPPING/MAILING INSTRUSTIONS, SEE THE LAST PAGE.

EQUIPMENT

You should have received the following:

- set of Sennheiser headphones with mini (1/8") stereo phone plug
- CDs, with 27 and 28 play list folders (total of 55 trials)
- 55 Trial Sheets
- envelopes with trial forms (first recipients) or 1 envelope (second recipients).

INSTRUCTIONS FOR TESTING

Please conduct this listening test in a quiet environment – free from as much environmental noise as possible (including both steady state and temporal impairments).

Each CD contains a copy of Media Player Classic, which can play the audio WAV files without installation or reconfiguration on your computer. It also contains a small ".inf" file that will automatically launch Media Player Classic when the CD is loaded in your computer's CD drive (if CD Auto run is enabled). Note: the player is intended for Windows PCs, not Mac computers. (However, as the program software runs *without* installation on the participant's computer, the file selection and playback must be controlled manually. We apologize for the inconvenience.)

First, connect your headphones directly to your computer's headphone jack. On desktop PCs this may be the Line Output jack, and may require unplugging external speakers.

Insert the CD labeled #1 in the CD drive. Media Player Classic will launch on the screen. Click File, Open File; and then the Browse button to open the file manager window. Navigate to the CD drive containing your audio test folders and open the folder 01. Click on file T1A, click OK, then OK again; the first audio track will begin playing. Note: the player will repeat the track until the stop ("■") button is clicked. The track may be replayed from the start by clicking the play ("►") button.

Make sure your volume is set to a "comfortable listening level". This is defined as a level that you can easily listen to, but one where you can hear impairments and minor differences. For each person this level will be different. Adjust the level by playing several of the tracks from the first folder. Please do not adjust your listening level once you have started the test. (Listening at different levels can affect your responses and make your listening experience invalid)

Get all your response sheets out (caution: postage stamps are in the envelope!), making sure that the first one in the pile says "Trial 1". It is crucial that you check each response sheet against the individual play list you are listening to. We do not have any way of ensuring that your data on a specific answer sheet matches the play list you have listened to except by your vigilance! For your convenience, at the bottom of each slider bar we have written out the name of the sound file you are judging. Please randomly check these against the sound files as you go along.

Start with Trial 1 in the folder named "1". Notice that there are five audio WAV files in each folder. The WAV files are labeled as follows:

A trial ID (a letter and a number) and a letter (indicating the specific WAV file). The important character for you to notice is the letter at the end. For the first trial you will see files "T1A", "T1B", "T1C", "T1D" and "T1E". These files correspond to the "A", "B", "C", "D", and "E" on your answer sheet marked "Trial _1_".

Listen to all of the WAV files from start to finish in order (A, B, C, D, E). After you are finished with the list, if you are undecided about your responses you may go back and play individual WAV files again in any order you choose. Record your responses on the response sheet. Do not proceed to the next play list until you have recorded all of your responses clearly. Please complete your answer sheet in two ways. First, as you listen, circle your answers on the vertical slider bars and check your responses in relationship to each other. Second, fill in a unique number in each box below the slider bar. If two answers are virtually identical, you must decide which sample is slightly better or worse, and assign a unique number to both. Number assignments can be extremely close (for example, 34 and 35), but not the same.

Do not return to a previous trial once you have moved on to another trial!

Please complete 27 trials on CD #1 and then take at least a 10-minute break. This is important so that you stay fresh during all of the trials. After the break, please finish the other 28 trials on CD #2.

Please do not take this test if you are:

- Tired, cranky or otherwise indisposed
- have a head cold or allergies (or any other condition that interferes with your ability to hear small differences)

- have too little time to complete the entire 55 trials in one sitting (2 listening sessions with a 10-minute break in between)
- Instead, save the test for another time during the week.

MAILING INSTRUCTIONS AFTER THE TEST IS COMPLETED

If you are one of the first 18 participants, you received two envelopes, one for your trial sheets and the other for a second participant. Your trial sheets should mailed using the postage-paid envelope to:

Ellyn G. Sheffield, PhD
Psychology Department, AW 406
Salisbury University
1101 Camden Avenue
Salisbury, MD 21801

Headphones should be re-shipped in the box provided. For some of you, that will mean mailing headphones, both CDs and envelope with blank forms to a second participant. For others, it will mean mailing headphones and completed forms back to NPR.

The first 18 participants will find a pre-printed mailing label for the second participant and sufficient postage for 1st Class mail in their envelope (marked #1 under the flap). Tape the enclosed mailing label for the second participant to the box, covering your original mailing label, and stick the 1st Class postage next to the label. After sealing the box, please drop the package at any US Post Office.

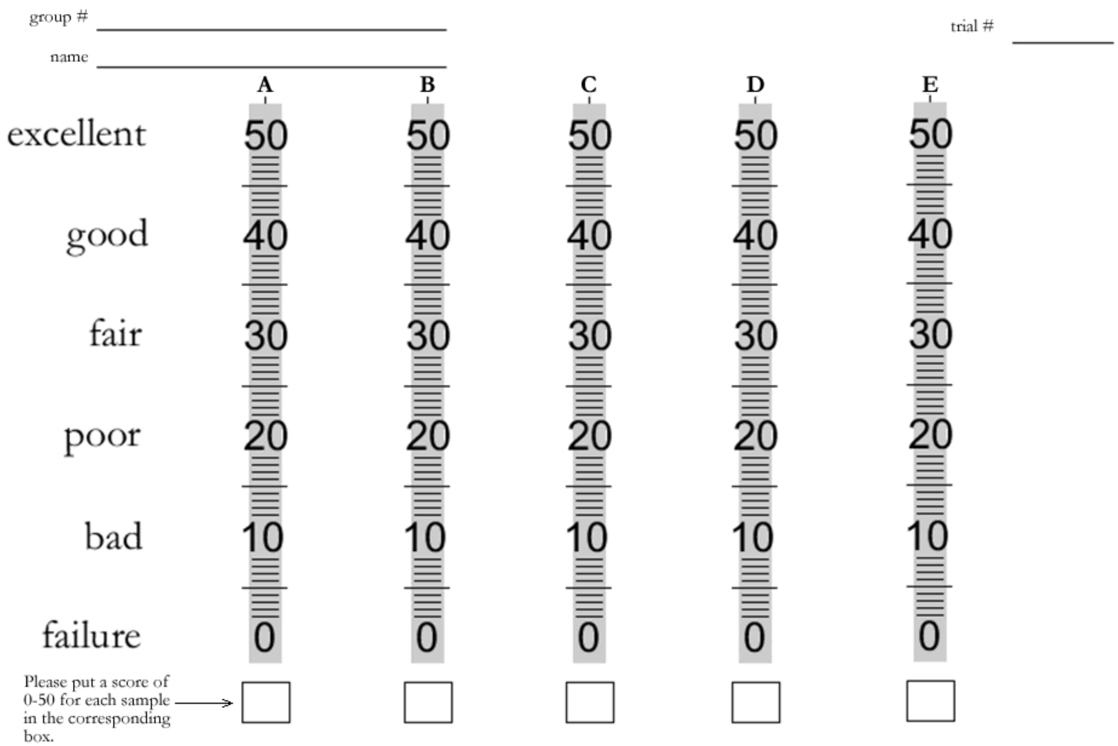
If you are one of the second group of participants, please cut out and tape the following address label and it to the box, covering the previous address labels:

John Kean
NPR Labs - National Public Radio
635 Massachusetts Ave. NW
Washington DC, 20001

The 1st Class postage for return to NPR is enclosed in the remaining envelope (marked "**#2**"). Please stick it to the box next to the label, seal the box and put it in the US Postal Service mail system for return to NPR.

If you cannot return your own completed form sheets within 7 days, please contact Ellyn Sheffield and alternative arrangements will be made.

Appendix C - Answer Sheets Used In Broadcast Industry Testing


group # ____________________ trial # ________

name ____________________

	A	B	C	D	E
excellent	50	50	50	50	50
good	40	40	40	40	40
fair	30	30	30	30	30
poor	20	20	20	20	20
bad	10	10	10	10	10
failure	0	0	0	0	0

Please put a score of 0-50 for each sample in the corresponding box.

Appendix D - Results By Cut And Receiver Bandwidth In Broadcast Industry Testing

Condition	Bandwidth	Median Receiver								
		Classical	Country	FemCom	FemSp	MaleCom	MaleSp	Pop	Rock	Sports
Unimpaired	5kHz	33.0	30.9	29.0	30.4	31.1	34.5	28.6	26.4	33.0
	6kHz	34.7	33.0	31.0	27.2	33.3	37.4	32.5	29.1	34.8
	7kHz	37.1	34.9	32.5	31.2	34.3	38.0	32.0	29.5	36.2
	8kHz	33.5	33.0	39.0	33.3		38.0	40.0	29.8	31.0
	10kHz	34.3	32.4	33.1	30.7	33.0	37.8	30.4	29.6	31.0
+15dB	5kHz	31.8	29.4	29.9	29.5	33.2	31.8	28.8	27.7	32.0
	6kHz	31.7	31.6	31.3	32.4	34.8	32.9	31.7	29.1	31.9
	7kHz	30.1	32.4	32.9	31.9	36.8	29.3	33.1	29.1	33.1
	8kHz	26.3	32.2	31.6	27.1	36.1	26.4	33.3	28.9	30.5
	10kHz	24.3	31.5	29.0	25.2	35.1	22.9	33.4	28.2	31.7
+6dB	5kHz	28.5	29.4	31.5	27.8	27.5	33.1	23.8	23.9	28.7
	6kHz	25.9	30.9	32.2	29.4	28.8	29.4	26.4	25.0	29.7
	7kHz	25.5	31.3	32.0	26.1	28.6	25.5	26.8	24.8	28.9
	8kHz	22.2	29.7	30.4	21.9	26.8	22.1	25.1	25.6	27.6
	10kHz	22.5	30.0	27.3	18.5	25.8	17.2	25.2	25.4	27.1
		80% Receiver								
		Classical	Country	FemCom	FemSp	MaleCom	MaleSp	Pop	Rock	Sports
Unimpaired	5kHz	30.7	30.3	29.2	33.1	28.5	32.4	28.1	28.7	35.3
	6kHz	34.5	35.8	33.5	34.9	32.5	36.0	31.0	29.0	38.1
	7kHz	36.3	37.5	36.0	37.9	36.2	37.0	33.9	33.0	40.6
	8kHz	34.7	37.1	37.9	37.8	36.5	37.0	33.3	34.2	39.4
	10kHz	33.5	36.6	36.0	37.3	32.8	37.5	34.7	33.7	39.2
+15dB	5kHz	28.3	31.8	31.4	27.6	31.6	31.8	30.8	27.4	36.0
	6kHz	26.9	35.3	34.5	30.6	33.8	32.2	33.4	30.1	37.5
	7kHz	29.6	36.4	35.7	31.7	37.2	33.2	35.4	32.6	38.2
	8kHz	27.2	37.6	36.1	25.0	35.5	27.4	34.0	34.2	36.4
	10kHz	25.5	37.7	34.3	23.8	36.3	26.0	34.3	32.6	36.2
+6dB	5kHz	31.8	30.0	22.9	24.3	22.2	20.0	24.8	26.6	31.1
	6kHz	30.2	28.5	22.2	22.7	22.3	19.1	23.8	24.2	30.2
	7kHz	25.3	28.0	22.5	22.6	20.2	15.6	23.8	24.9	29.4
	8kHz	22.9	28.3	19.9	20.3	19.9	15.1	23.8	25.2	28.7
	10kHz	22.0	27.6	18.3	17.5	19.8	12.6	23.4	25.8	29.1

Appendix E - Experimenter Script For Consumer Test

Experimenter Script for Consumer Test

Welcome to our session! Today you will be participating in a listening experiment, which should last about 2 hours. You will be listening to music and speech samples over a loudspeaker. We aren't going to tell you what you are listening to right now, but we can tell you that your responses are going to help the radio industry find the best way of transmitting radio shows to you.

Your basic mission in this test is to tell us whether you hear differences in pairs of samples. We will play 2 samples, side-by-side, and you will be asked to report a few things: (a) whether you heard a difference between the samples; (b) how much of a difference you heard; and (c) whether either or both of the samples would be unacceptable to you if you were listening on your car or home radio. Occasionally you will come across 2 samples that you believe are equal in quality. This is ok. We know that the differences are very small and that you may feel like you are "guessing". Other times the differences will be large, and you'll be very sure of yourself.

A few details:
1. You can change the listening level during your first trial, but you may not change that level during the rest of the test. So, make sure the level you are listening at is comfortable before you start! I will help you determine this level when you start.

2. When you are done with a section, you should take a break! We really don't want you going through the test too quickly, as you may start to fatigue.

3. The test is long. Pace yourself and try to answer as quickly as possible after you have made a decision. On the other hand, don't rush through without thinking – you will not have an opportunity to revisit previous trials once you've pushed the "continue" button.

Experimenter:

1. *Make sure of the following:*
    a. *The listener is positioned at the back end of the rug (so that the consumer is sitting about 6 feet from the speaker)*
    b. *The curtains are drawn on BOTH walls*
    c. *The speaker is turned on*
    d. *The keyboard is taken away during the test, so that the consumer only has a mouse to use*
    e. *ALL CELL PHONES MUST BE TURNED OFF DURING THE TEST (that includes the consumer's phone as well as your own phone)*
    f. *The door to the outside hall is shut at all times while the test is running.*
2. *Co to My computer – click on Local Disk (C:) – click on AMSTG – Click on test tool.*

Appendix F Listener Test Data Arranged by Receiver Bandwidth

Rcvr.	D/U	Freq. Comb. (kHz)	Neither Sample	A not B	B not A	Both Sample
20%	30 dB	5/10	18	13	64	185
		5/7	22	15	58	185
		7/10	23	16	17	224
	15dB	5/10	35	30	51	164
		5/7	29	21	42	188
		7/10	31	30	24	195
	6 dB	5/10	80	66	22	112
		5/7	83	29	18	150
		7/10	94	40	16	130
Median	30 dB	5/10	19	8	25	228
		5/7	12	8	19	241
		7/10	17	11	11	241
	15 dB	5/10	19	53	14	194
		5/7	14	16	21	229
		7/10	26	53	10	191
	6 dB	5/10	45	82	16	137
		5/7	44	39	19	178
		7/10	64	60	14	142
20%	30 dB	5/10	15	11	32	222
		5/7	17	8	22	232
		7/10	11	9	16	244
	15 dB	5/10	40	50	25	165
		5/7	35	20	26	199
		7/10	45	42	11	182
	6 dB	5/10	78	75	12	115
		5/7	94	22	8	156
		7/10	100	45	12	123
Grand Total			**1110**	**872**	**625**	**4592**

Appendix G Listener Data Arranged by Transmission Bandwidth

Trans. BW	Rcvr.	D/U Ratio	Commercial	Music	Speech	Sports
5 kHz	20%	30dB	2	13	10	2
		15dB	4	16	28	3
		6dB	12	25	50	8
	Median	30dB	1	5	7	1
		15dB	2	14	54	1
		6dB	10	33	78	3
	80%	30dB		4	9	5
		15dB	10	17	45	1
		6dB	17	29	50	6
7 kHz	20%	30dB	16	28	20	11
		15dB	11	20	35	10
		6dB	7	17	29	6
	Median	30dB	6	12	8	7
		15dB	9	15	44	6
		6dB	14	17	41	7
	80%	30dB	5	14	9	3
		15dB	13	17	32	4
		6dB	6	17	31	4
10 kHz	20%	30dB	10	44	16	11
		15dB	12	42	6	11
		6dB	4	21	3	9
	Median	30dB	3	17	6	9
		15dB	2	11	2	7
		6dB	1	19		7
	80%	30dB	3	23	13	10
		15dB	6	17	3	9
		6dB		8		6

Appendix H Table of Consumer Test results by individual cut

		Classical			Country			FemaleCommercial		
		5kHz	7kHz	10kHz	5kHz	7kHz	10kHz	5kHz	7kHz	10kHz
20%	+30dB	0.27	0.38	0.35	0.18	0.32	0.51	0.14	0.43	0.43
	+15dB	0.28	0.38	0.34	0.18	0.38	0.44	0.23	0.38	0.38
	+6dB	0.47	0.38	0.16	0.26	0.38	0.36	0.38	0.38	0.25
Median	+30dB	0.27	0.41	0.33	0.33	0.38	0.30	0.31	0.43	0.27
	+15dB	0.43	0.34	0.23	0.35	0.31	0.34	0.31	0.41	0.28
	+6dB	0.51	0.35	0.14	0.40	0.28	0.32	0.35	0.47	0.18
80%	+30dB	0.28	0.32	0.40	0.32	0.33	0.36	0.20	0.39	0.41
	+15dB	0.39	0.29	0.32	0.29	0.28	0.43	0.30	0.42	0.28
	+6dB	0.49	0.38	0.13	0.43	0.35	0.22	0.58	0.38	0.03

		FemaleSpeech			MaleSpeech			Rock			Sports		
		5kHz	7kHz	10kHz	5kHz	7kHz	10kHz	5kHz	7kHz	10kHz	5kHz	7kHz	10kHz
20%	+30dB	0.23	0.44	0.33	0.28	0.40	0.32	0.19	0.34	0.47	0.18	0.36	0.47
	+15dB	0.42	0.51	0.08	0.37	0.47	0.17	0.19	0.33	0.48	0.15	0.43	0.42
	+6dB	0.50	0.43	0.08	0.55	0.40	0.05	0.20	0.35	0.45	0.27	0.36	0.38
Median	+30dB	0.36	0.38	0.27	0.25	0.42	0.33	0.24	0.45	0.31	0.20	0.38	0.43
	+15dB	0.48	0.47	0.05	0.51	0.43	0.06	0.33	0.37	0.31	0.24	0.33	0.43
	+6dB	0.58	0.42	0.01	0.63	0.34	0.03	0.27	0.42	0.32	0.34	0.39	0.27
80%	+30dB	0.26	0.38	0.37	0.21	0.40	0.39	0.21	0.39	0.40	0.25	0.31	0.44
	+15dB	0.52	0.40	0.08	0.53	0.40	0.07	0.30	0.35	0.35	0.23	0.36	0.42
	+6dB	0.58	0.39	0.03	0.63	0.35	0.03	0.43	0.33	0.23	0.30	0.33	0.37

Appendix I - Table of Complete Results of Magnitude of Preference

			10kHz	5kHz	7kHz	All 3 kHz	None of the 3 kHz
Classical	20%	+30dB	0.05	0.04	0.05	0.83	0.03
		+15dB	0.05	0.07	0.06	0.76	0.07
		+6dB	0.01	0.14	0.06	0.50	0.29
	Median	+30dB	0.03	0.02	0.03	0.88	0.05
		+15dB	0.02	0.05	0.03	0.84	0.06
		+6dB	0.02	0.20	0.08	0.49	0.22
	80%	+30dB	0.05	0.00	0.02	0.91	0.03
		+15dB	0.03	0.08	0.06	0.76	0.08
		+6dB	0.03	0.13	0.08	0.62	0.15
Country	20%	+30dB	0.18	0.03	0.08	0.67	0.03
		+15dB	0.10	0.03	0.06	0.75	0.06
		+6dB	0.05	0.06	0.04	0.63	0.23
	Median	+30dB	0.05	0.01	0.03	0.88	0.04
		+15dB	0.03	0.04	0.05	0.83	0.05
		+6dB	0.05	0.05	0.01	0.71	0.18
	80%	+30dB	0.05	0.03	0.05	0.83	0.05
		+15dB	0.07	0.01	0.06	0.78	0.08
		+6dB	0.06	0.02	0.05	0.68	0.20
FemCommercial	20%	+30dB	0.09	0.01	0.13	0.73	0.03
		+15dB	0.11	0.03	0.08	0.71	0.07
		+6dB	0.03	0.10	0.06	0.54	0.27
	Median	+30dB	0.03	0.02	0.04	0.88	0.03
		+15dB	0.02	0.02	0.08	0.85	0.04
		+6dB	0.02	0.08	0.11	0.70	0.09
	80%	+30dB	0.03	0.00	0.04	0.90	0.03
		+15dB	0.05	0.08	0.11	0.72	0.04
		+6dB	0.01	0.14	0.04	0.17	0.64
FemSpeech	20%	+30dB	0.06	0.03	0.10	0.71	0.11
		+15dB	0.03	0.16	0.18	0.46	0.18
		+6dB	0.02	0.21	0.13	0.23	0.42
	Median	+30dB	0.03	0.03	0.03	0.88	0.05
		+15dB	0.03	0.18	0.21	0.47	0.12
		+6dB	0.00	0.27	0.21	0.21	0.32
	80%	+30dB	0.06	0.03	0.04	0.81	0.07
		+15dB	0.04	0.14	0.12	0.35	0.35
		+6dB	0.03	0.22	0.17	0.23	0.35
MaleSpeech	20%	+30dB	0.08	0.06	0.07	0.59	0.21
		+15dB	0.04	0.08	0.08	0.53	0.26
		+6dB	0.03	0.21	0.09	0.22	0.45
	Median	+30dB	0.03	0.03	0.04	0.80	0.10
		+15dB	0.01	0.25	0.16	0.48	0.11
		+6dB	0.00	0.37	0.15	0.24	0.24
	80%	+30dB	0.05	0.04	0.04	0.81	0.06
		+15dB	0.01	0.21	0.15	0.30	0.33
		+6dB	0.01	0.18	0.07	0.15	0.59
Rock	20%	+30dB	0.13	0.05	0.09	0.65	0.08
		+15dB	0.19	0.03	0.07	0.63	0.09
		+6dB	0.11	0.01	0.05	0.58	0.26
	Median	+30dB	0.06	0.03	0.04	0.78	0.09
		+15dB	0.06	0.02	0.04	0.81	0.08
		+6dB	0.11	0.02	0.05	0.70	0.13
	80%	+30dB	0.08	0.03	0.04	0.77	0.08
		+15dB	0.03	0.06	0.04	0.79	0.08
		+6dB	0.01	0.08	0.01	0.67	0.24
Sports	20%	+30dB	0.09	0.02	0.09	0.77	0.03
		+15dB	0.10	0.03	0.08	0.73	0.08
		+6dB	0.07	0.07	0.06	0.58	0.23
	Median	+30dB	0.08	0.01	0.05	0.83	0.03
		+15dB	0.05	0.02	0.05	0.84	0.04
		+6dB	0.06	0.03	0.06	0.76	0.10
	80%	+30dB	0.08	0.04	0.03	0.81	0.04
		+15dB	0.08	0.01	0.03	0.85	0.03
		+6dB	0.06	0.04	0.03	0.78	0.09
Grand Total			0.05185	0.07487	0.0713	0.655	0.1468

Appendix J – Tested Receivers Ranked by Audio Bandwidth

Receiver Category	Brand	Radio Description	Model	-10 dB Freq. (Hz)	-10 dB Freq. %ile	SNR, CCIR (dB)	SNR %ile	THD, 400 Hz (%)	THD %ile	Color Coding
Shelf/mini system	RCA	Bookshelf System	RS23035	2600	0%	41	55%	2.4	75%	20th percentile target
Clock	Audiovox	Electronics CD AM/FM Alarm Clock	CE256	2800	3%	21	0%	2.3	62%	median target
HD Radio	JVC	AM/FM/HD	KD-SHX900	3000	6%	30	17%	0.8	20%	80th percentile target
Portable CD boombox	Sony	400W Mini Hi-Fi Stereo CD Changer	MHCGX450	3200	10%	49	82%	1.3	31%	
Home stereo	Pioneer	600W 6.1-Ch. A/V Home Theater	VSX-D814K	3200	10%	31	20%	2.6	79%	
Portable CD boombox	Aiwa	Hi-Fi Mini System - Silver	JAX-S77	3300	17%	47	79%	0.7	10%	20th percentile receiver
Portable CD boombox	Panasonic	Mini AM/FM Stereo Cassette Recorder	RXFS430A	3400	20%	40	51%	0.7	10%	
Portable CD boombox	CCRadio Plu	Ccrane	CCRadio Plus	3400	20%	29	13%	3.5	96%	
OEM auto	Chevrolet	2002 Suburban 2500	15071234	3500	27%	27	6%	1.3	31%	
Home stereo	Sony	700W 7.1-Ch. A/V Home Theater	STRDE697	3500	27%	45	72%	2.3	62%	
Car in-dash CD	Pioneer	AM/FM/CD	DEH-P6600	3600	34%	51	93%	1.1	27%	
Shelf/mini system	Sony	Desktop Micro System	CMTNE3	3600	34%	42	58%	1.9	51%	
Portable CD boombox	Emerson	Portable CD Boombox	PD6810	3600	34%	46	75%	2	55%	
Shelf/mini system	Bose	Wave Music System	CD/AM/FM	3800	44%	31	20%	2.6	79%	
Car in-dash cassette	JVC	AM/FM/Cassette	KS-FX490	3900	48%	50	89%	0.5	0%	median receiver
Home stereo	Yamaha	600W 6.1-Ch. A/V Home Theater	HTR-5740	4100	51%	43	62%	2.3	62%	
OEM auto	Chevrolet	2000 Tahoe	15765006	4200	55%	33	31%	1.7	44%	
OEM auto	Chevrolet	1995 Camaro	16175961	4300	58%	31	20%	2.3	62%	
Car in-dash cassette	Sony	AM/FM Cassette	XR-F5100X	4400	62%	52	100%	0.8	20%	
Home stereo	Denon	AM/FM multimedia	DRA-295	4400	62%	34	37%	2.2	58%	
Clock	Boston Acou	Recepter Digital AM/FM Dual Alarm	Recepter-P	4500	68%	33	31%	4.1	100%	
Car in-dash CD	Kenwood	AM/FM/CD	KDC-3025	4800	72%	49	82%	0.6	3%	
OEM auto	Ford	2002 Mustang	2L2T-18C868-D	6100	82%	44	65%	0.7	10%	
OEM auto	Honda	2002 Accord	P/N - 39100-S84	4800	72%	39	48%	1.8	48%	
Portable CD boombox	Grundig	AM/FM Shortwave World Band (wide)	S350	5000	79%	35	44%	1.5	41%	
HD Radio	Panasonic	CD/MP3/WMA with built-in HD Tuner	CQ-CB9900U	6400	86%	51	93%	0.6	3%	80th percentile receiver
Clock	Sima	NOAA Alert AM/FM & Alarm Clock	WX-39	6600	89%	21	0%	3.3	93%	
Shelf/mini system	Panasonic	CD Bookshelf Stereo	SC-EN7	8500	93%	44	65%	2.7	86%	
Clock	Curtis	CD AM/FM Stereo Clock	CR4966	9300	96%	27	6%	1.4	37%	
Portable CD boombox	GE	Super Radio III (wide)	360678	9600	100%	34	37%	3.2	89%	

Appendix K - Receiver Measurements

4.1 Home Stereos

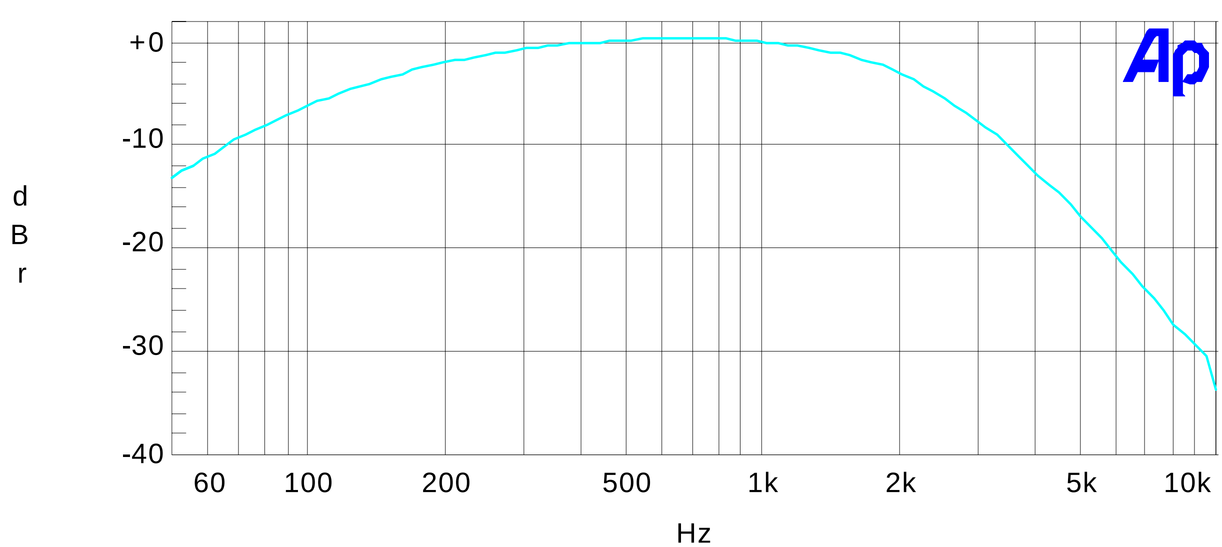
4.1.1 Sony STR-DE697

Category	Home Stereo
AGC Threshold (dBm)	-75
RF Overload (dBm)	-10
RF Test level (dBm)	-43
SNR, unweighted (dB)	42
THD, 400 Hz (%)	2.3
THD, 50 Hz (%)	22.1
SNR, CCIR (dB)	-45
-3 dB Frequency (Hz)	2000
-10 dB Frequency (Hz)	3500

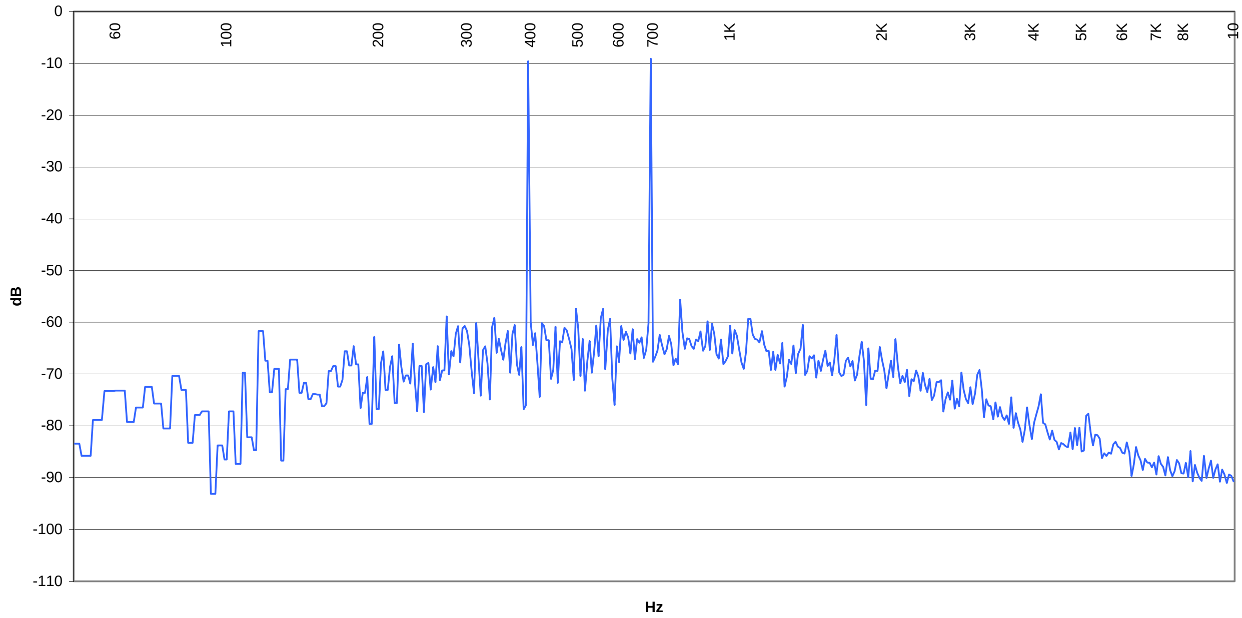
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	43	29	20	15
-10	45	27	26	21
7	45	34	26	21
-7	45	40	30	26
6	-	38	28	22
-6	-	41	32	26
5	-	40	30	24
-5	-	41	34	28

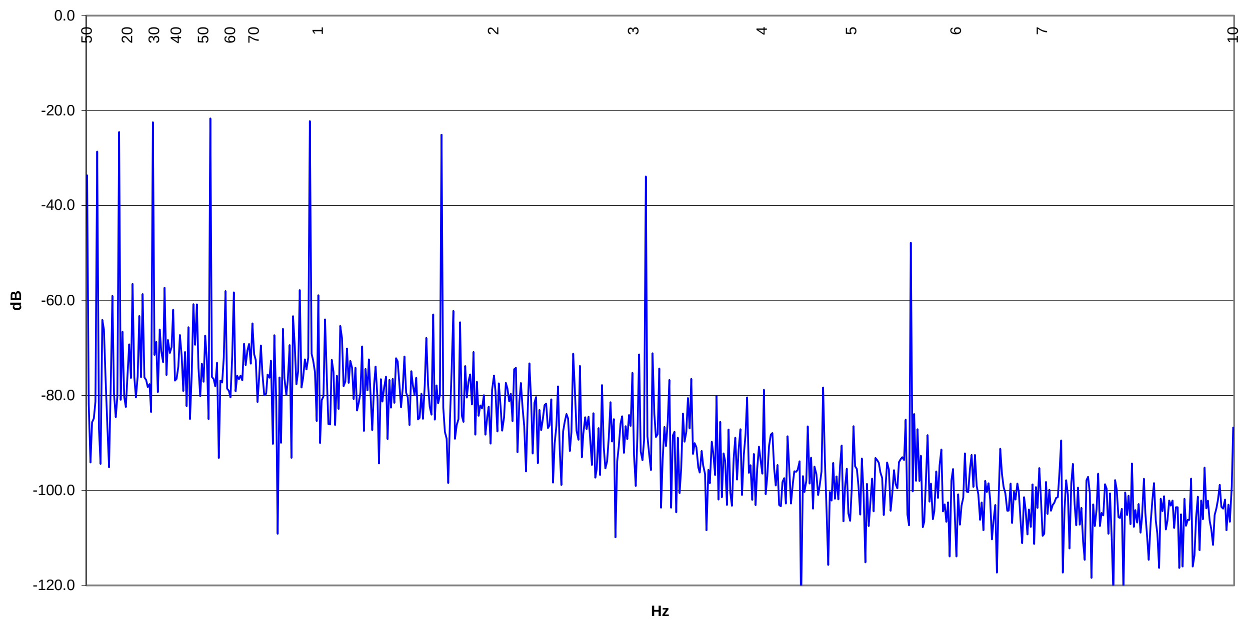
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



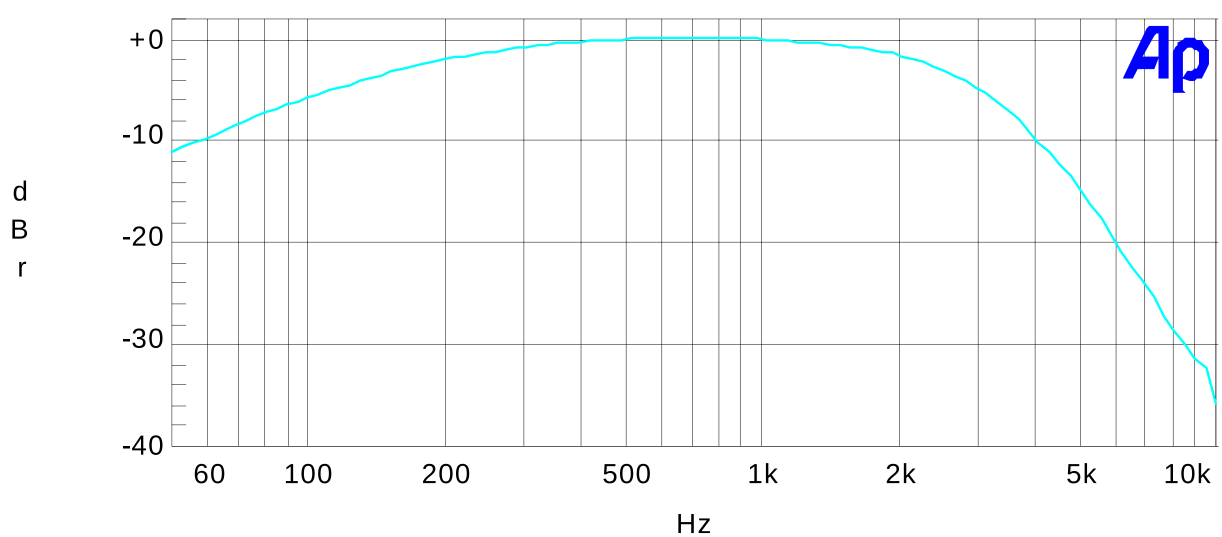
4.1.2 Yamaha HTR-5740

Category	Home Stereo
AGC Threshold (dBm)	-75
RF Overload (dBm)	0
RF Test level (dBm)	-38
SNR, unweighted (dB)	37
THD, 400 Hz (%)	2.3
THD, 50 Hz (%)	13.5
SNR, CCIR (dB)	-43
-3 dB Frequency (Hz)	2500
-10 dB Frequency (Hz)	4100

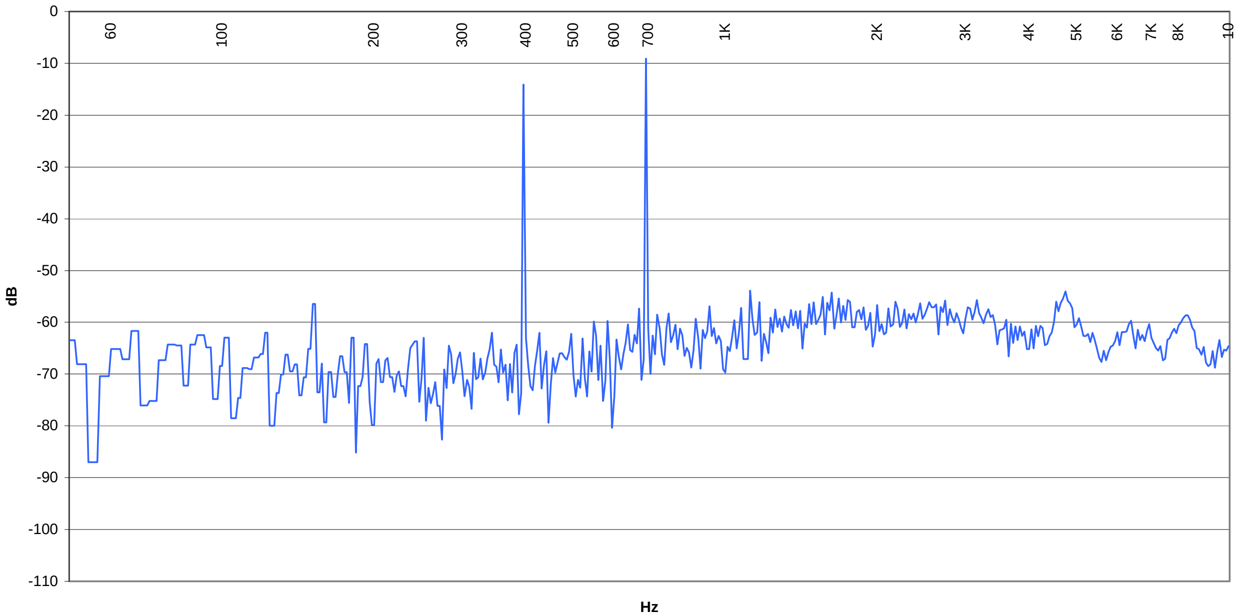
Psophometer-Based Adjacent-Channel Interference

LPF kHz	D/U (dB)			
	+30	+15	+6	0
10	41	30	21	16
-10	41	32	22	17
7	42	35	26	20
-7	42	36	28	22
6	42	38	29	24
-6	43	39	32	25
5	-	40	32	26
-5	-	41	34	28

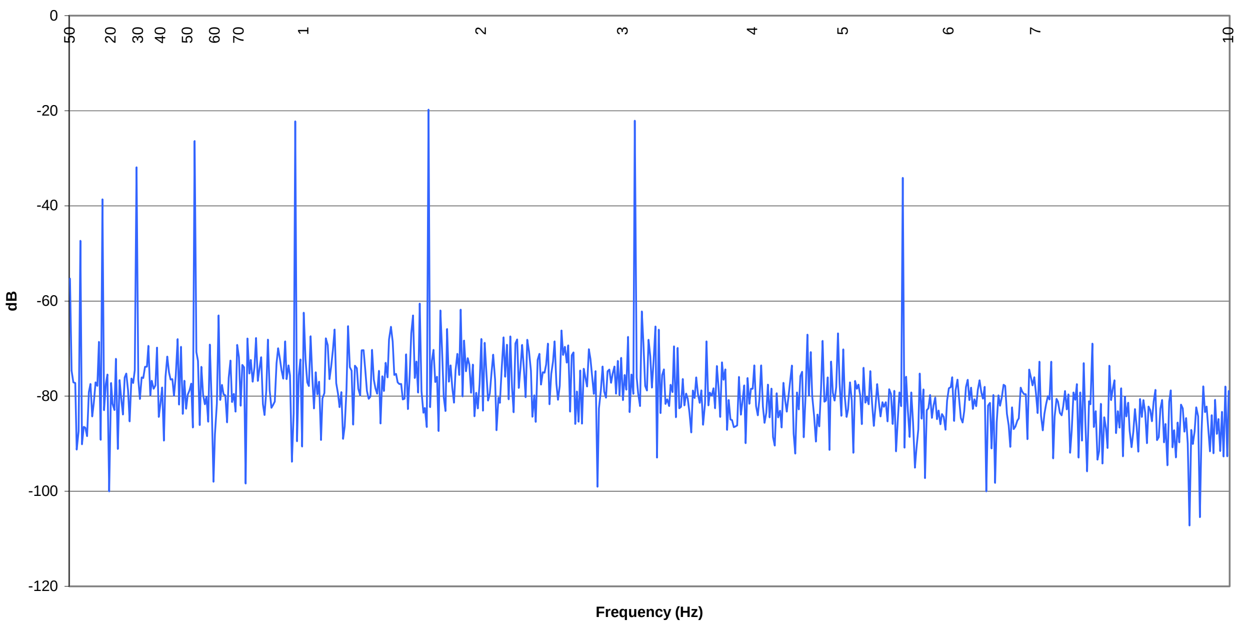
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



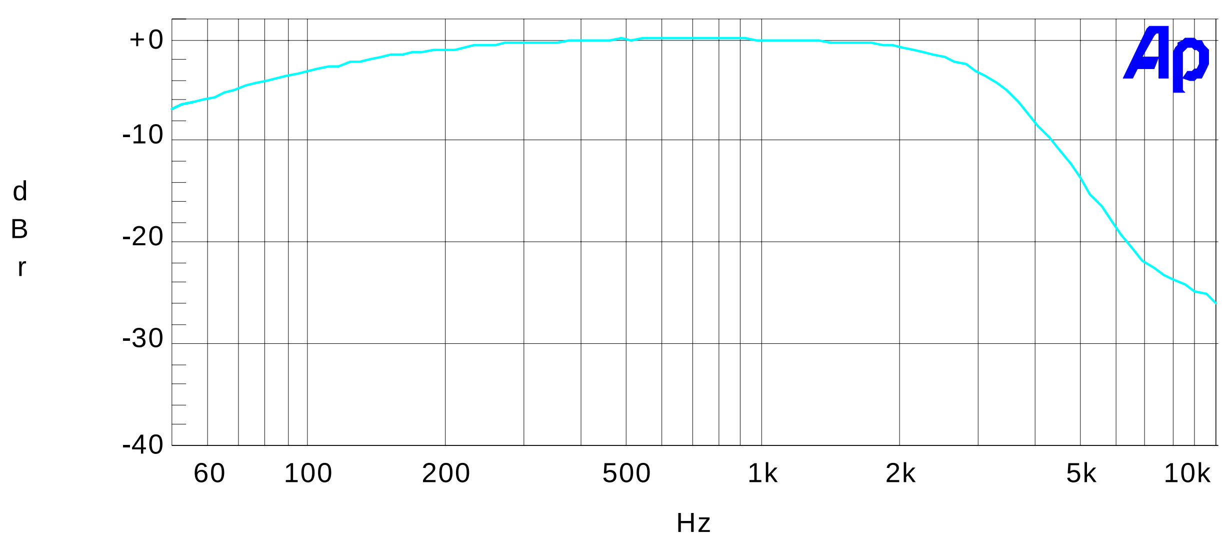
4.1.3 Denon DRA-295

Category	Home Stereo
AGC Threshold (dBm)	-75
RF Overload (dBm)	-35
RF Test level (dBm)	-55
SNR, unweighted (dB)	36
THD, 400 Hz (%)	2.2
THD, 50 Hz (%)	7.1
SNR, CCIR (dB)	-34
-3 dB Frequency (Hz)	3000
-10 dB Frequency (Hz)	4400

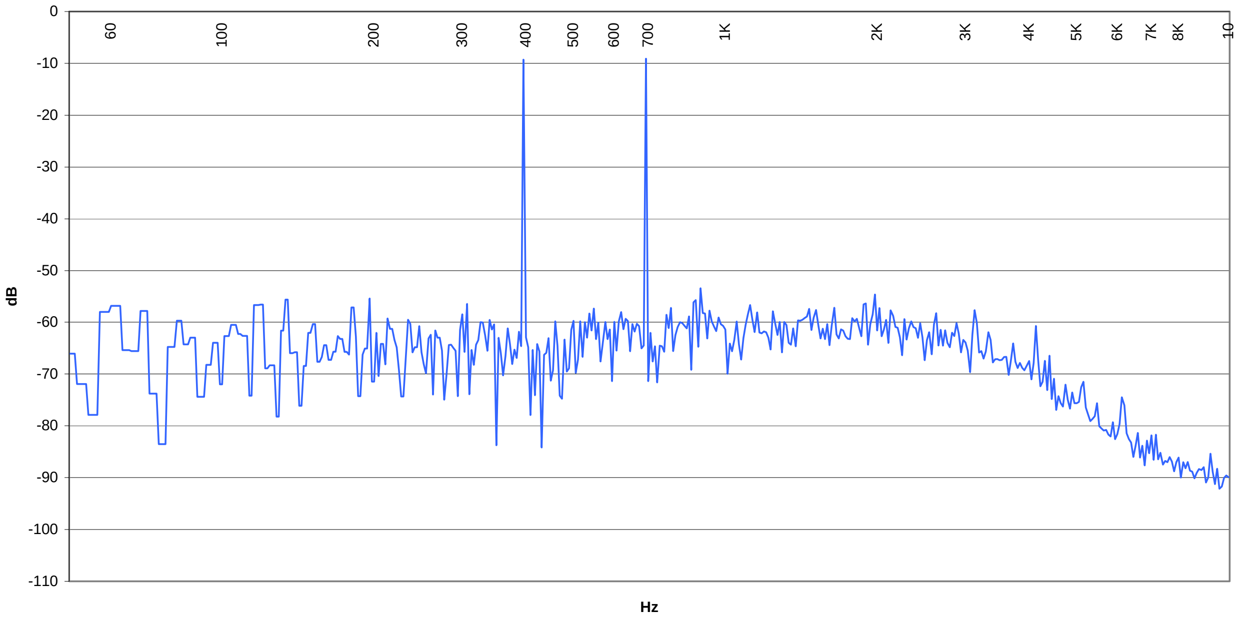
Psophometer-Based Adjacent-Channel Interference

LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	-	27	19	14
-10	-	32	23	19
7	-	32	22	19
-7	-	33	28	23
6	-	32	26	21
-6	-	34	31	26
5	-	33	28	23
-5	-	34	32	30

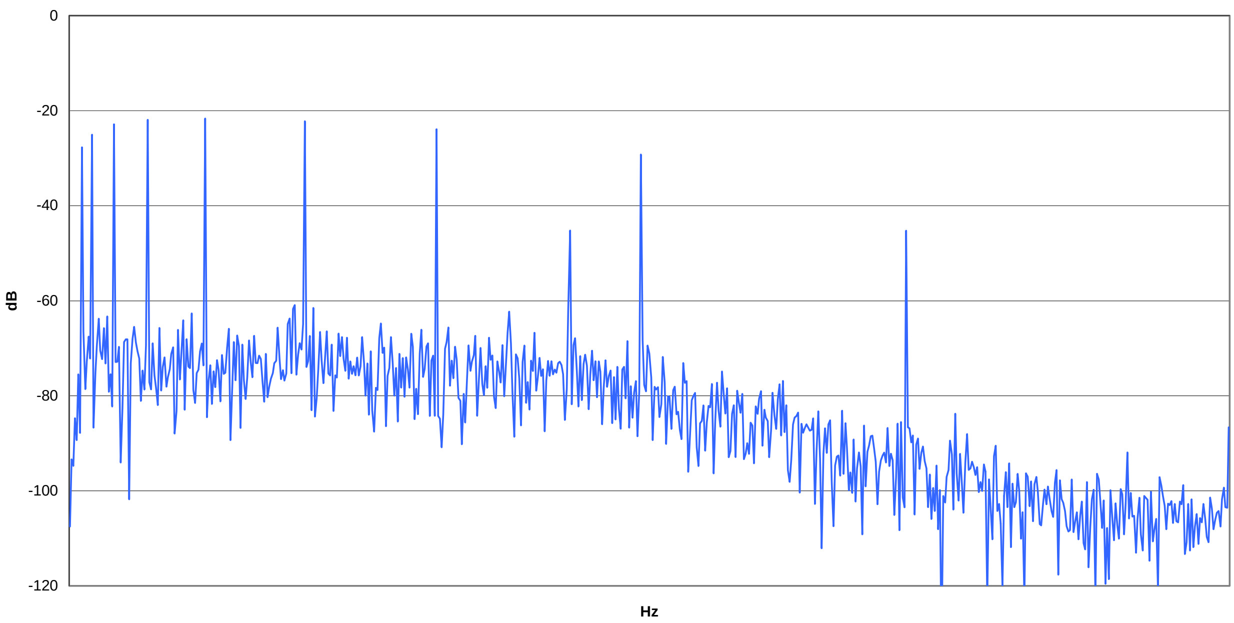
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



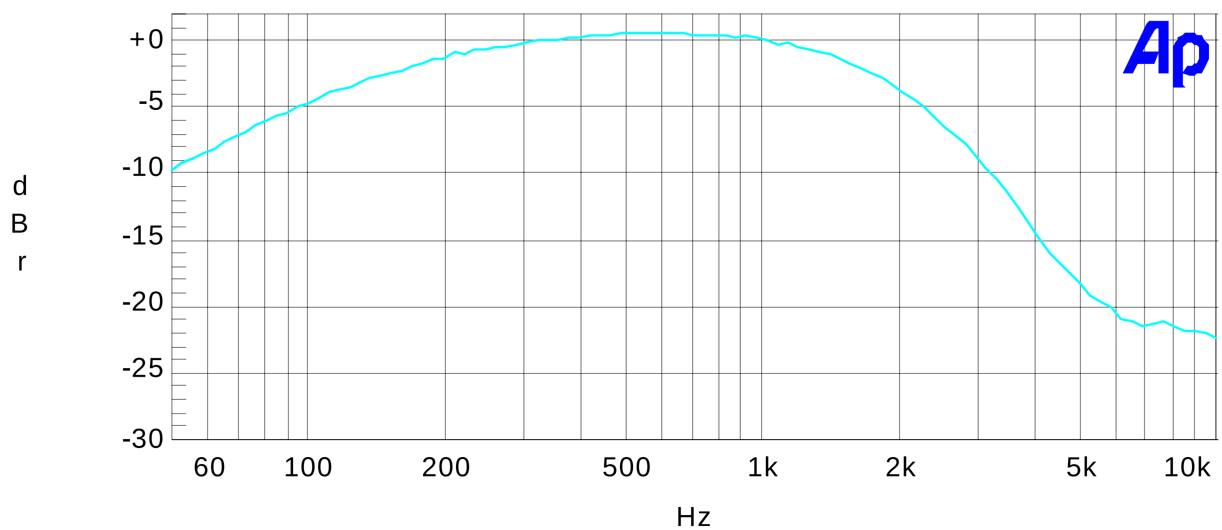
4.1.4 Pioneer VSX-D814K

Category	Home Stereo
AGC Threshold (dBm)	-75
RF Overload (dBm)	-35
RF Test level (dBm)	-55
SNR, unweighted (dB)	28
THD, 400 Hz (%)	2.6
THD, 50 Hz (%)	10.1
SNR, CCIR (dB)	-31
-3 dB Frequency (Hz)	1900
-10 dB Frequency (Hz)	3200

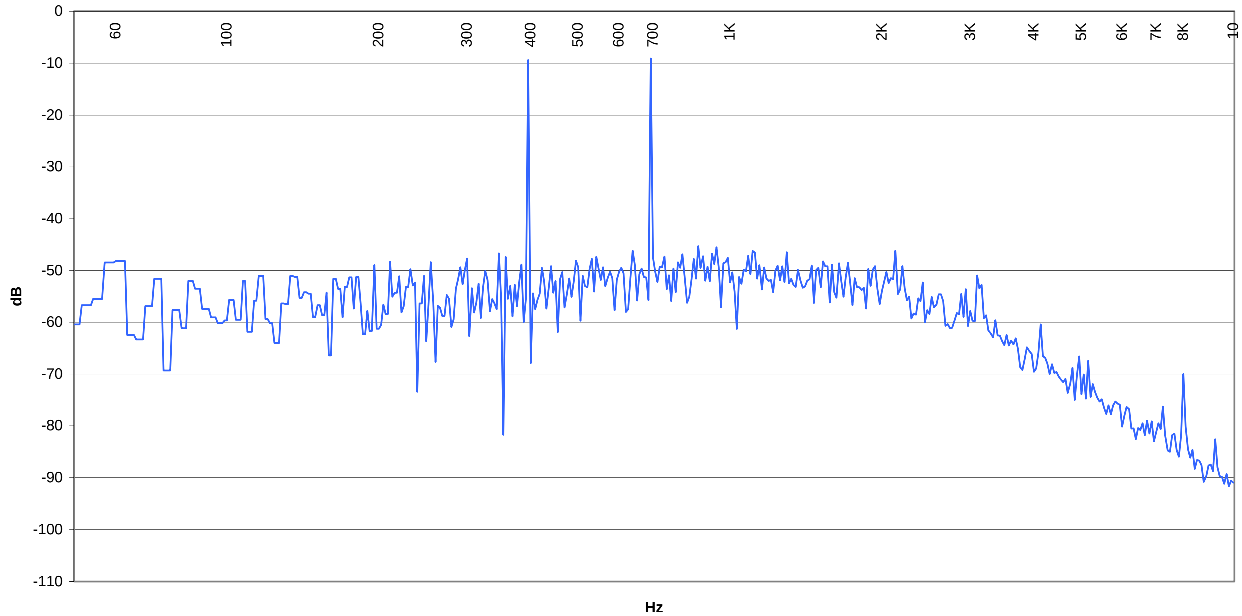
Psophometer-Based Adjacent-Channel Interference

LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	-	28	23	18
-10	-	30	25	21
7	-	31	27	25
-7	-	31	30	28
6	-	-	29	26
-6	-	-	31	29
5	-	-	30	27
-5	-	-	-	-

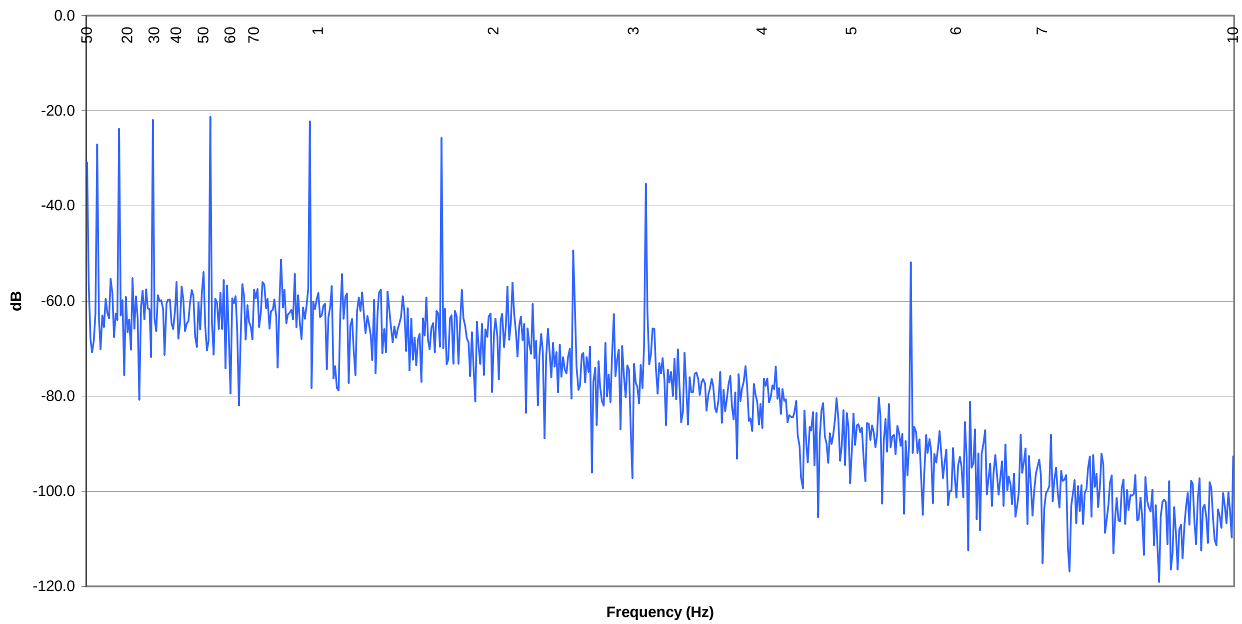
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



4.2 Shelf / Mini Systems

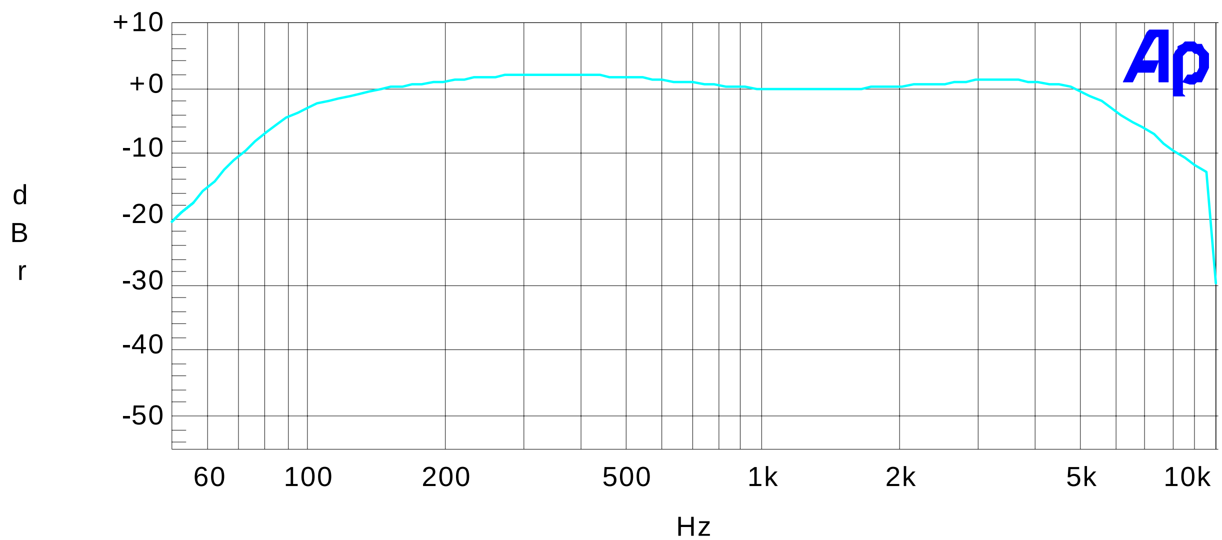
4.2.1 Panasonic SC-EN7

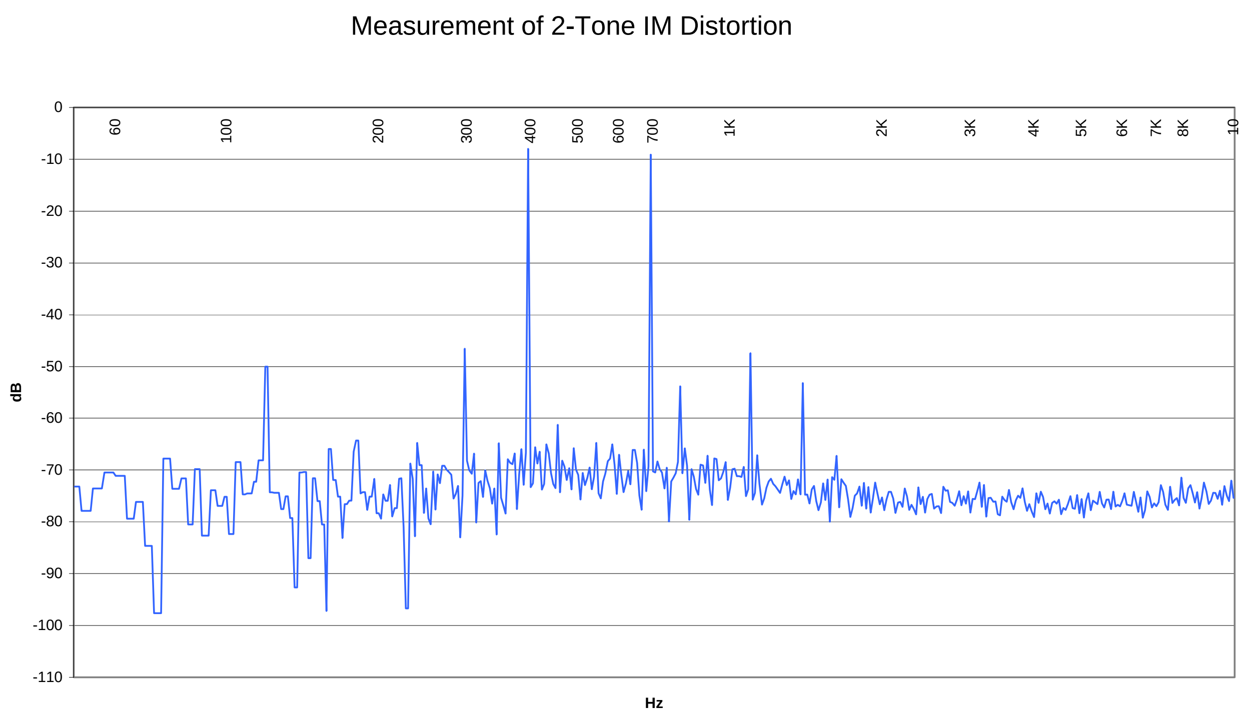
Category	Shelf/mini
AGC Threshold (dBm)	-65
RF Overload (dBm)	5
RF Test level (dBm)	-30
SNR, unweighted (dB)	42
THD, 400 Hz (%)	2.7
THD, 50 Hz (%)	42.9
SNR, CCIR (dB)	-44
-3 dB Frequency (Hz)	5900
-10 dB Frequency (Hz)	8500

Psophometer-Based Adjacent-Channel Interference

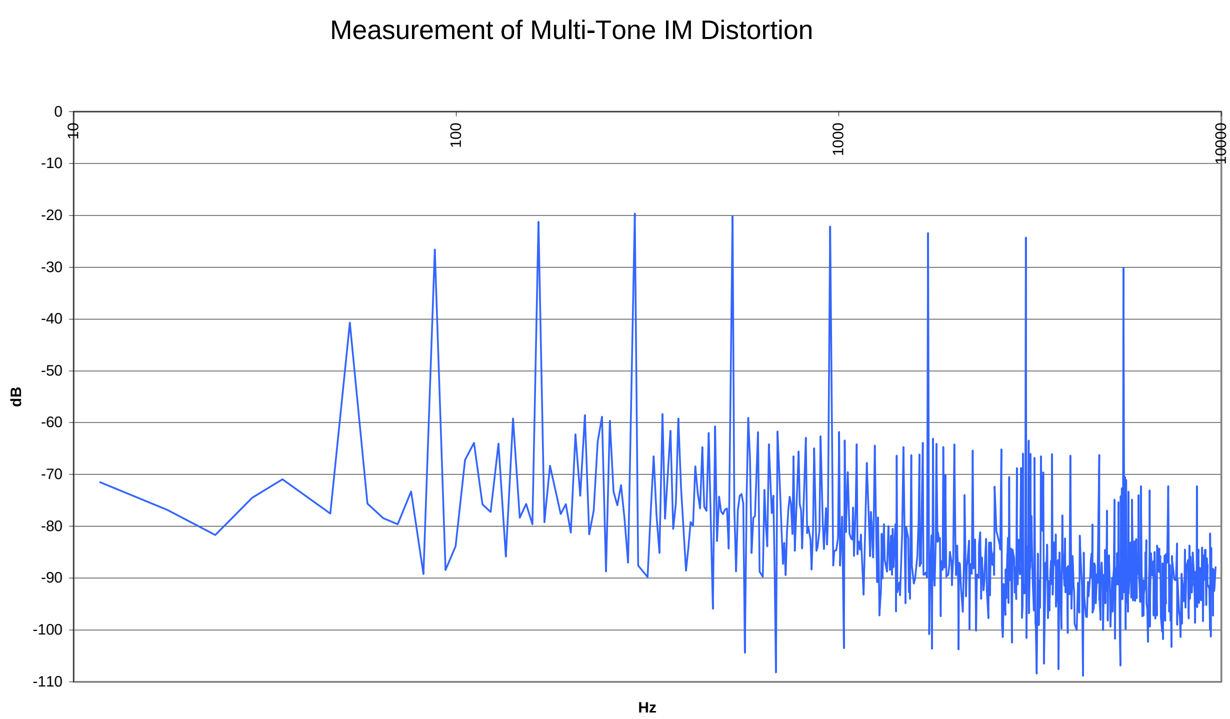
LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	36	23	15	8
-10	34	22	10	6
7	36	23	13	8
-7	35	20	11	7
6	36	24	15	9
-6	36	21	11	8
5	37	23	14	9
-5	36	22	12	8

Measurement of AM Frequency Response





Measurement of 2-Tone IM Distortion
dB
Hz
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
60
100
200
300
400
500
600
700
1K
2K
3K
4K
5K
6K
7K
8K
10



Measurement of Multi-Tone IM Distortion
dB
Hz
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
10
100
1000
10000

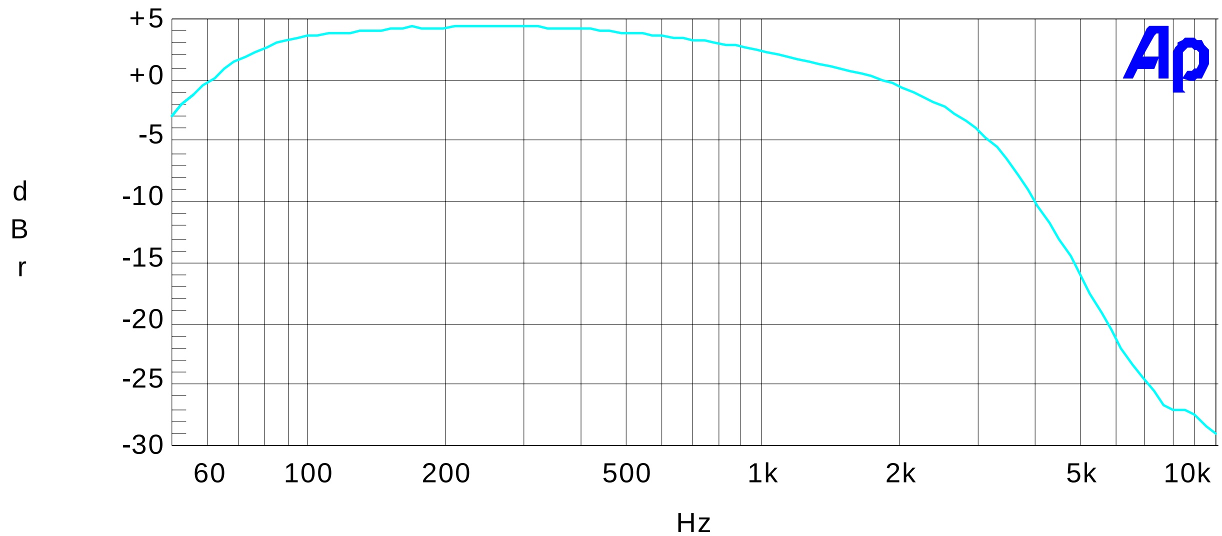
4.2.2 Sony CMT-NE3

Category	Shelf/mini
AGC Threshold (dBm)	-60
RF Overload (dBm)	5
RF Test level (dBm)	-33
SNR, unweighted (dB)	44
THD, 400 Hz (%)	1.9
THD, 50 Hz (%)	24.2
SNR, CCIR (dB)	-42
-3 dB Frequency (Hz)	2100
-10 dB Frequency (Hz)	3600

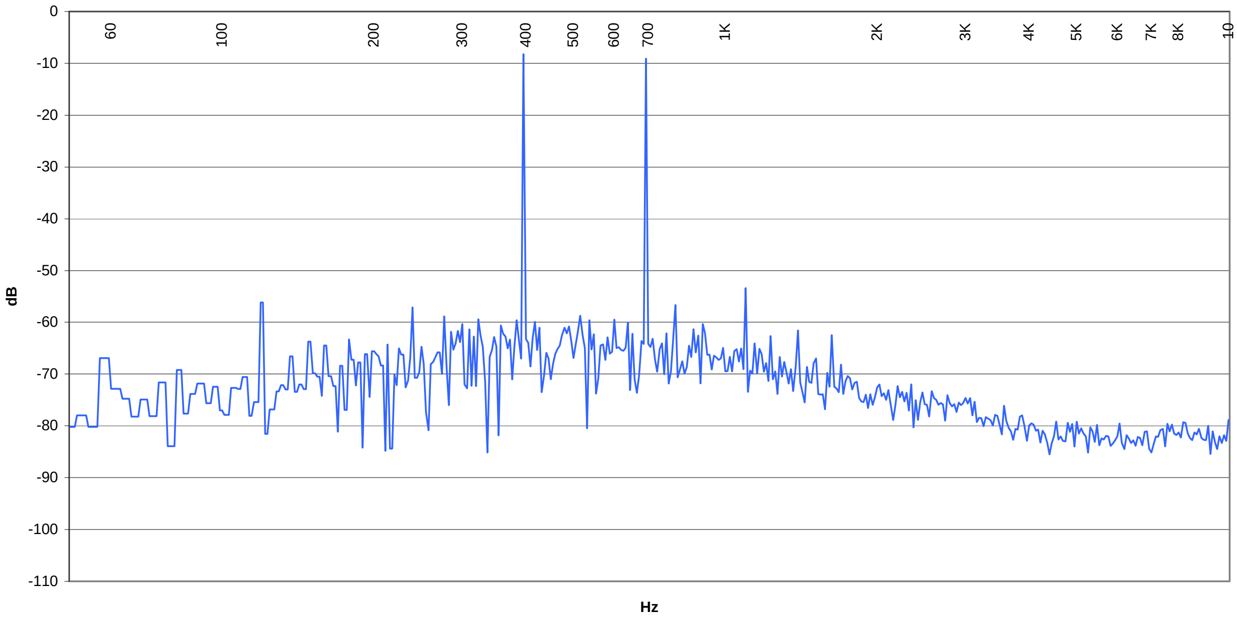
Psophometer-Based Adjacent-Channel Interference

LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	-	35	28	23
-10	-	30	20	14
7	-	40	34	28
-7	-	34	26	19
6	-	41	36	31
-6	-	37	28	22
5	-	-	38	33
-5	-	39	31	26

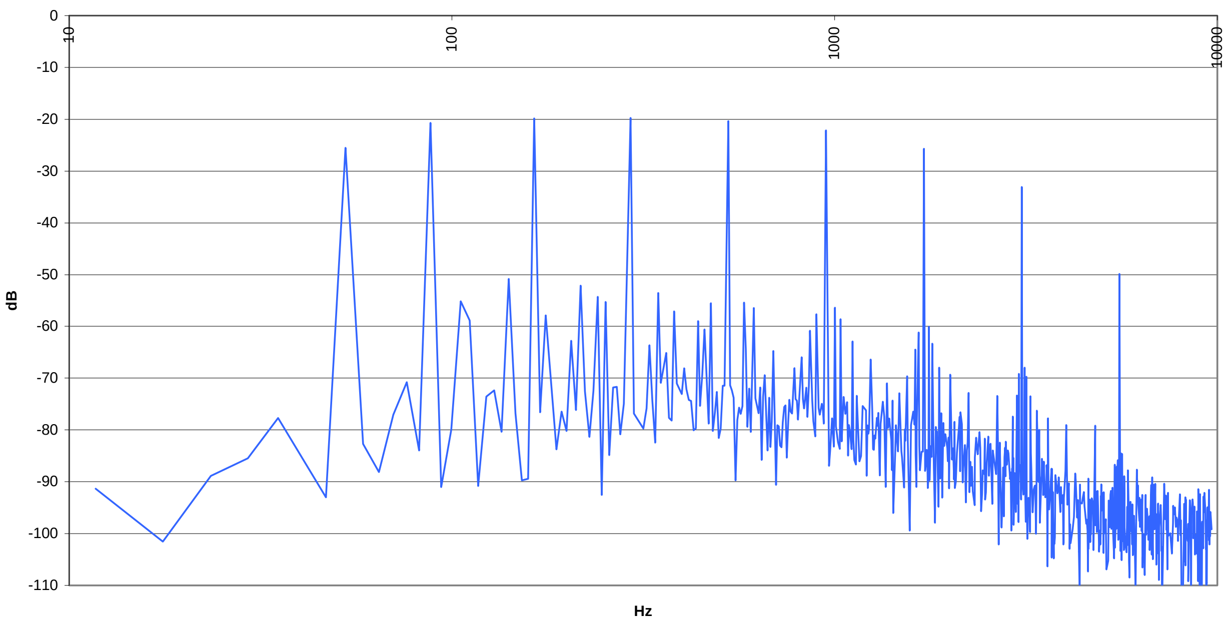
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



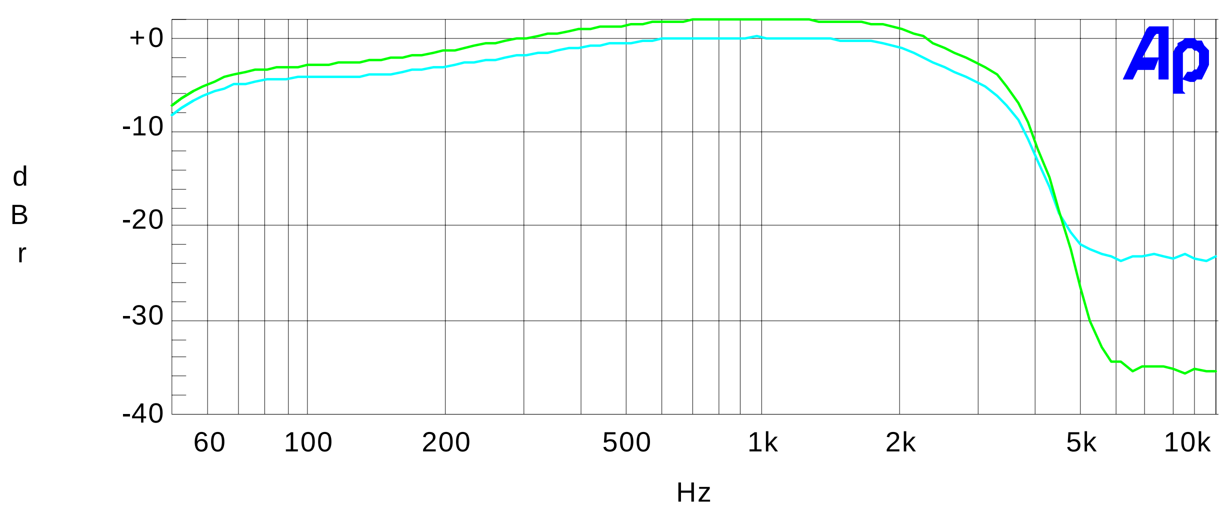
4.2.3 Bose Wave Radio

Category	Shelf/mini
AGC Threshold (dBm)	-75
RF Overload (dBm)	-45
RF Test level (dBm)	-60
SNR, unweighted (dB)	33
THD, 400 Hz (%)	2.6
THD, 50 Hz (%)	9.2
SNR, CCIR (dB)	-31
-3 dB Frequency (Hz)	2500
-10 dB Frequency (Hz)	3800

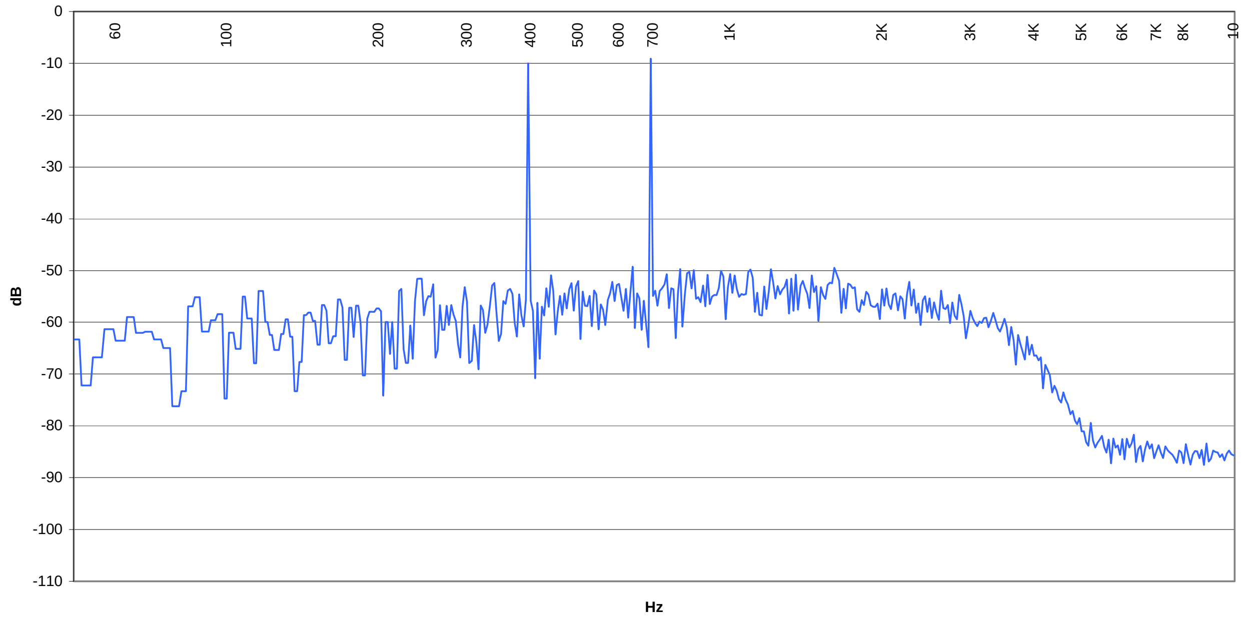
Psophometer-Based Adjacent-Channel Interference

LPF kHz	D/U (dB)			
	+30	+15	+6	0
10	31	29	25	21
-10	31	27	19	14
7	-	30	30	29
-7	-	29	25	21
6	-	-	30	30
-6	-	-	29	28
5	-	-	30	31
-5	-	-	30	31

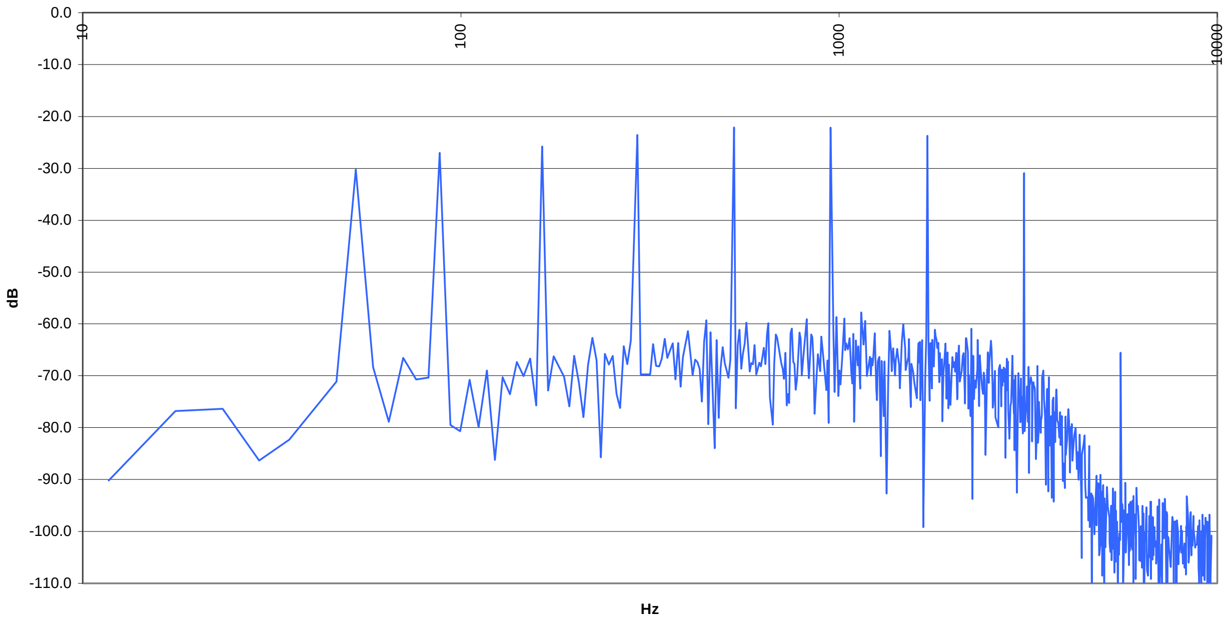
Frequency Response at -60 dBm (cyan) & -30 dBm (green)



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



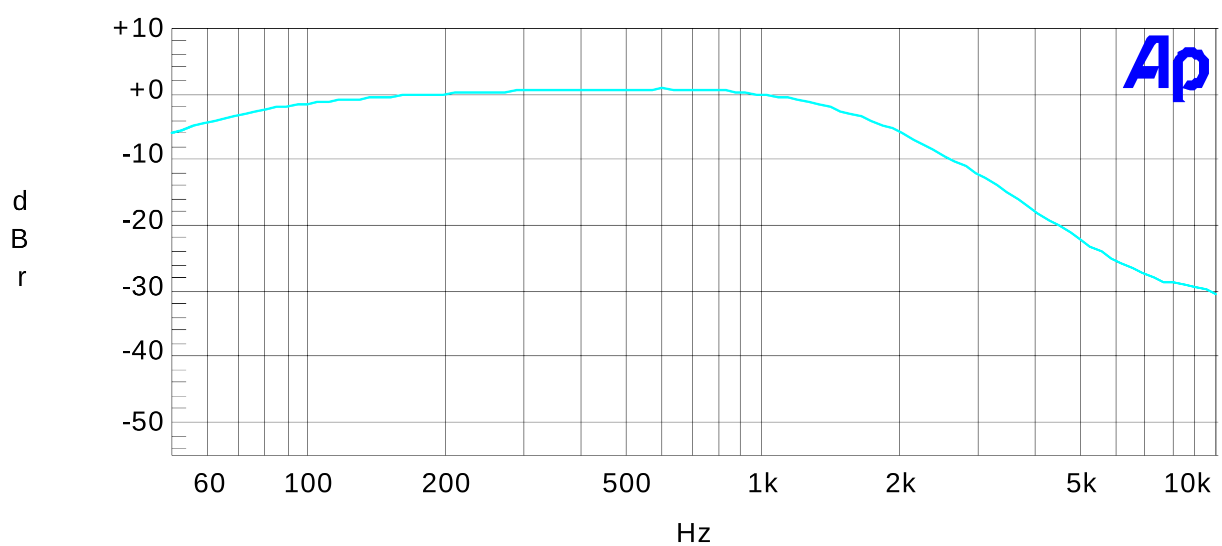
4.2.4 RCA RS23035

Category	Shelf/mini
AGC Threshold (dBm)	-50
RF Overload (dBm)	-5
RF Test level (dBm)	-28
SNR, unweighted (dB)	40
THD, 400 Hz (%)	2.4
THD, 50 Hz (%)	12.7
SNR, CCIR (dB)	-41
-3 dB Frequency (Hz)	1600
-10 dB Frequency (Hz)	2600

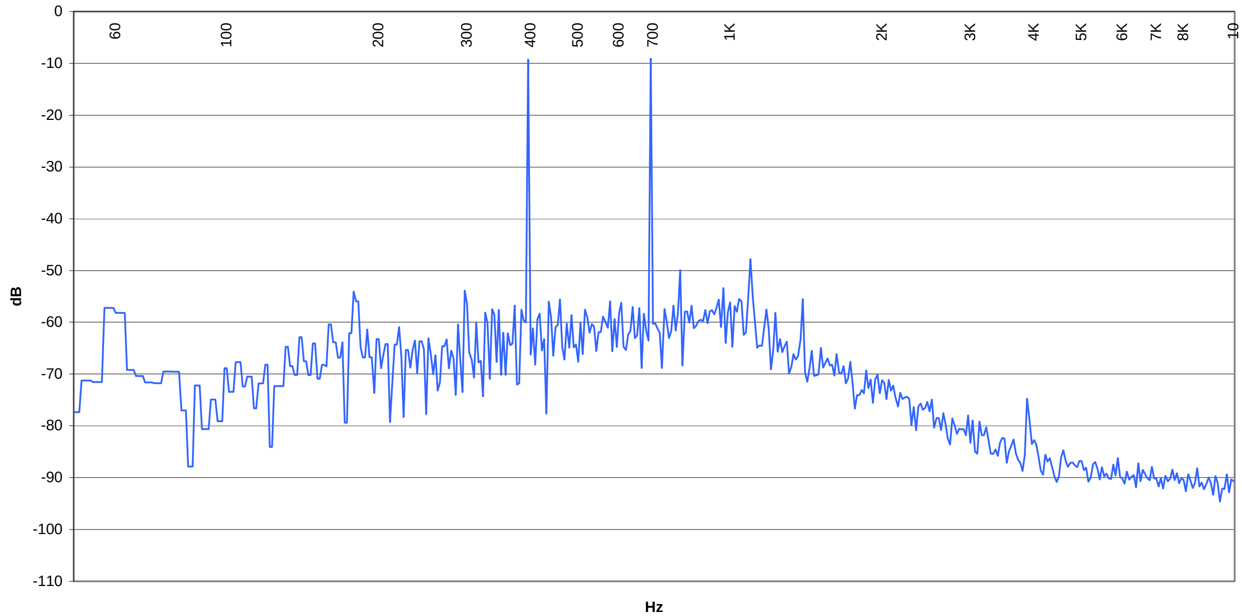
Psophometer-Based Adjacent-Channel Interference

LPF kHz	D/U (dB)			
	+30	+15	+6	0
10	-	35	32	23
-10	-	38	34	27
7	-	38	33	31
-7	-	39	38	34
6	-	39	36	32
-6	-	40	39	35
5	-	39	36	30
-5	-	40	39	37

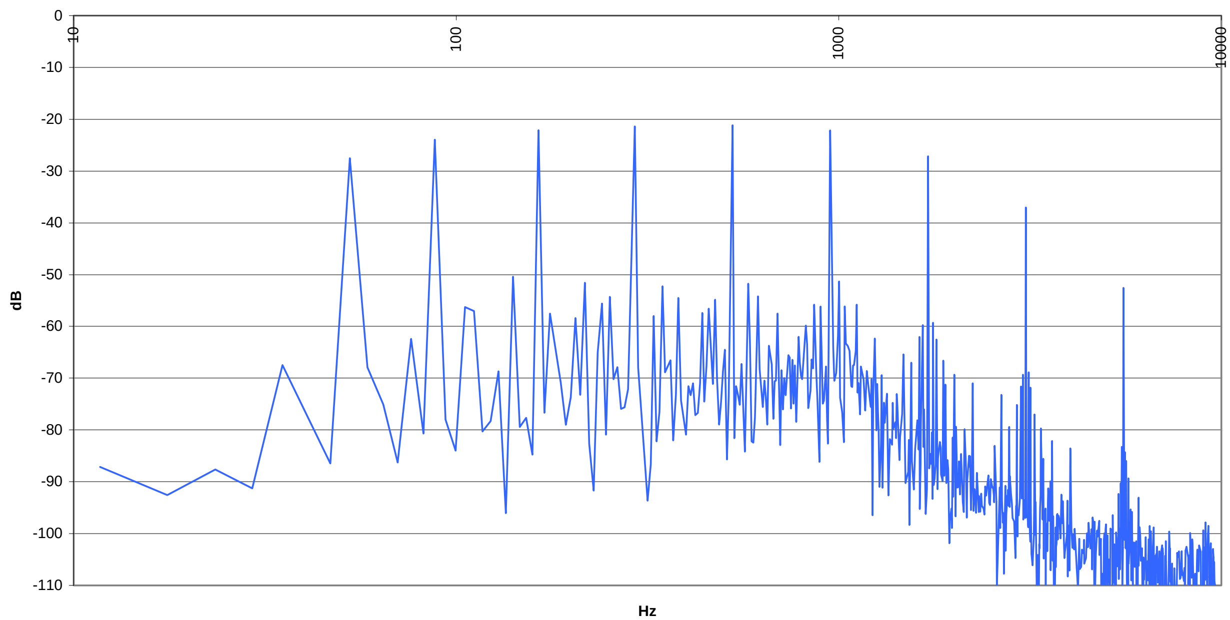
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



4.3 Portable / CD Boom boxes

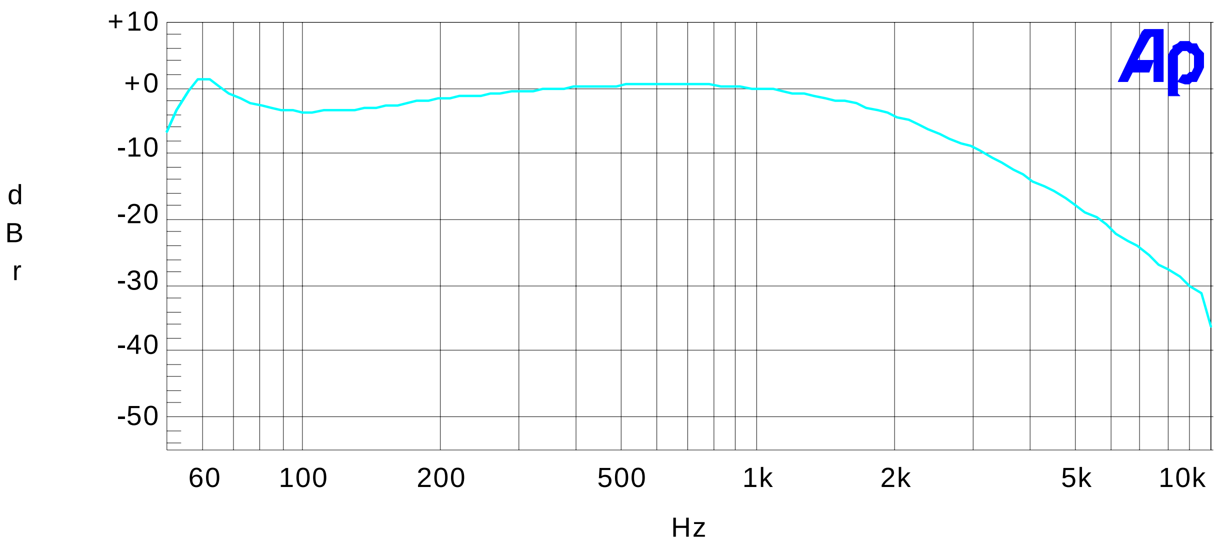
4.3.1 Sony MHCGX450

Category	Portable CD Boom box
AGC Threshold (dBm)	-75
RF Overload (dBm)	-10
RF Test level (dBm)	-40
SNR, unweighted (dB)	50
THD, 400 Hz (%)	1.3
THD, 50 Hz (%)	1.5
SNR, CCIR (dB)	-49
-3 dB Frequency (Hz)	1800
-10 dB Frequency (Hz)	3200

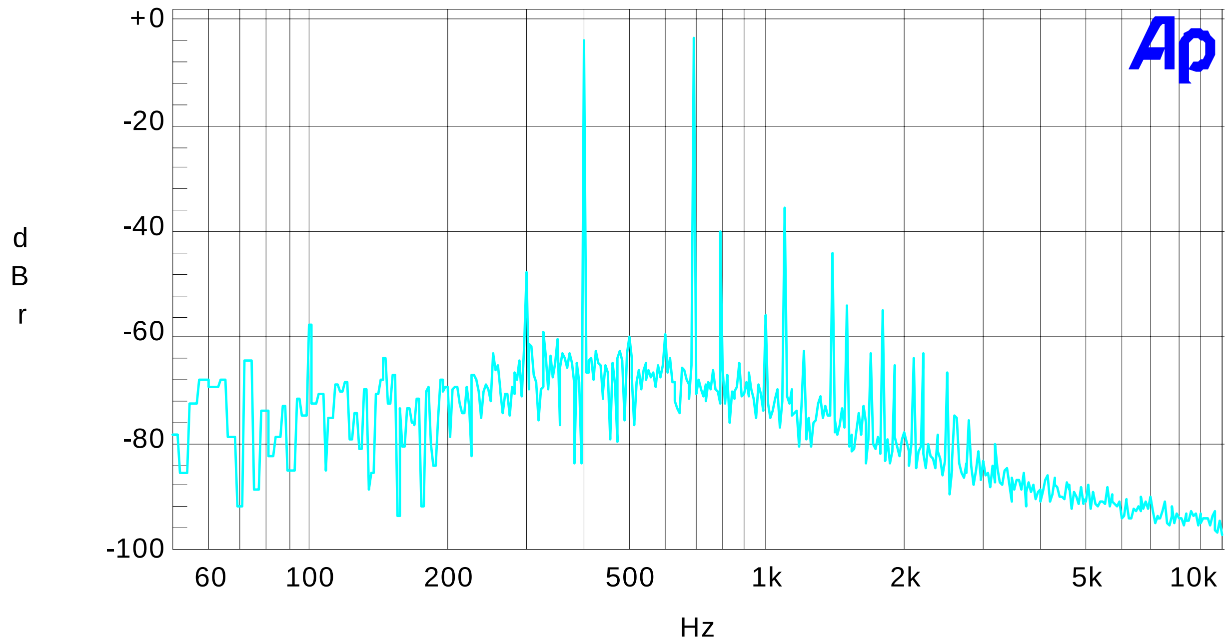
Psophometer-Based Adjacent-Channel Interference

LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	48	37	25	20
-10	46	34	25	17
7	48	40	32	26
-7	48	37	29	22
6	-	43	35	30
-6	-	40	30	25
5	-	44	37	26
-5	-	42	32	31

Measurement of AM Frequency Response

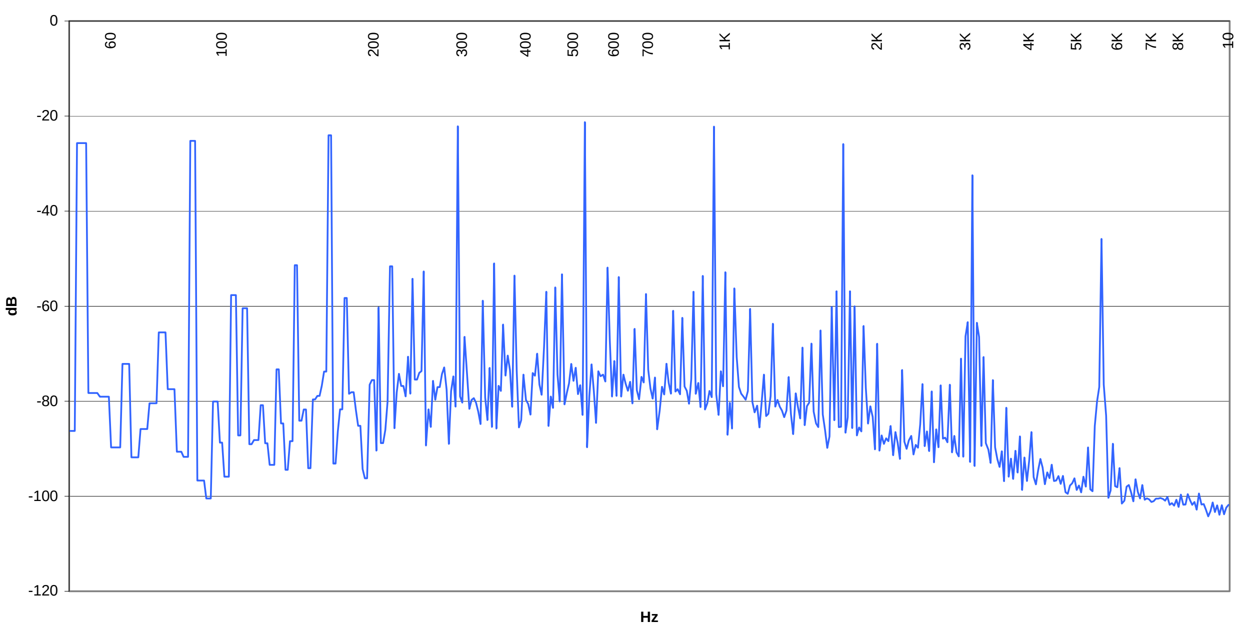


Measurement of 2-Tone IM Distortion



Note: Readings on vertical scale above are 5 dB high.

Measurement of 10-Tone IM Distortion



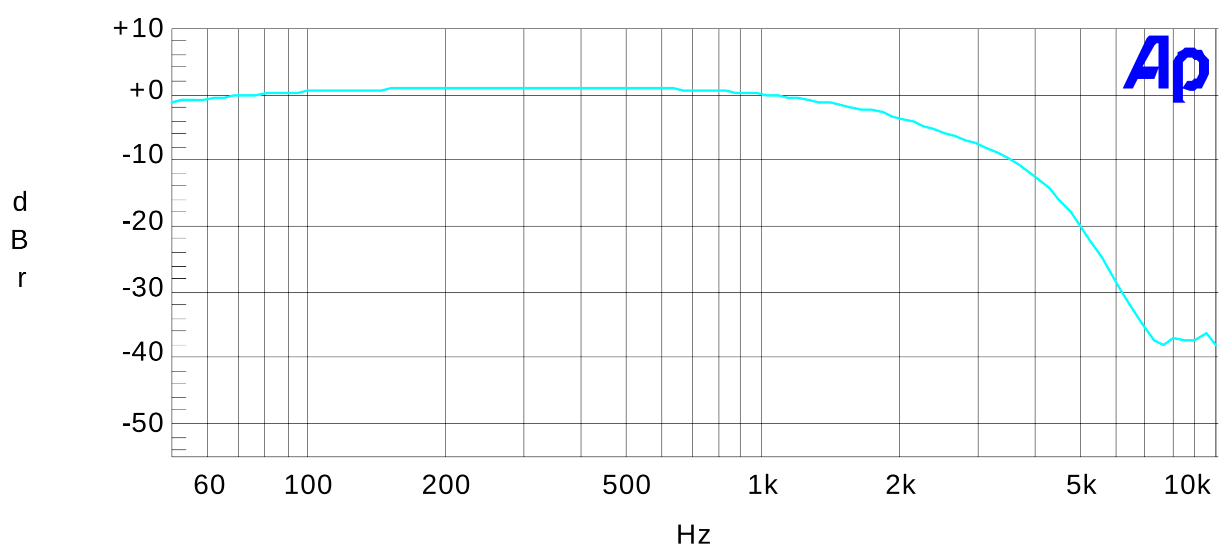
4.3.2 Emerson PD6810

Category	Portable CD Boom box
AGC Threshold (dBm)	-40
RF Overload (dBm)	-15
RF Test level (dBm)	-28
SNR, unweighted (dB)	34
THD, 400 Hz (%)	2.0
THD, 50 Hz (%)	5.4
SNR, CCIR (dB)	-46
-3 dB Frequency (Hz)	1900
-10 dB Frequency (Hz)	3600

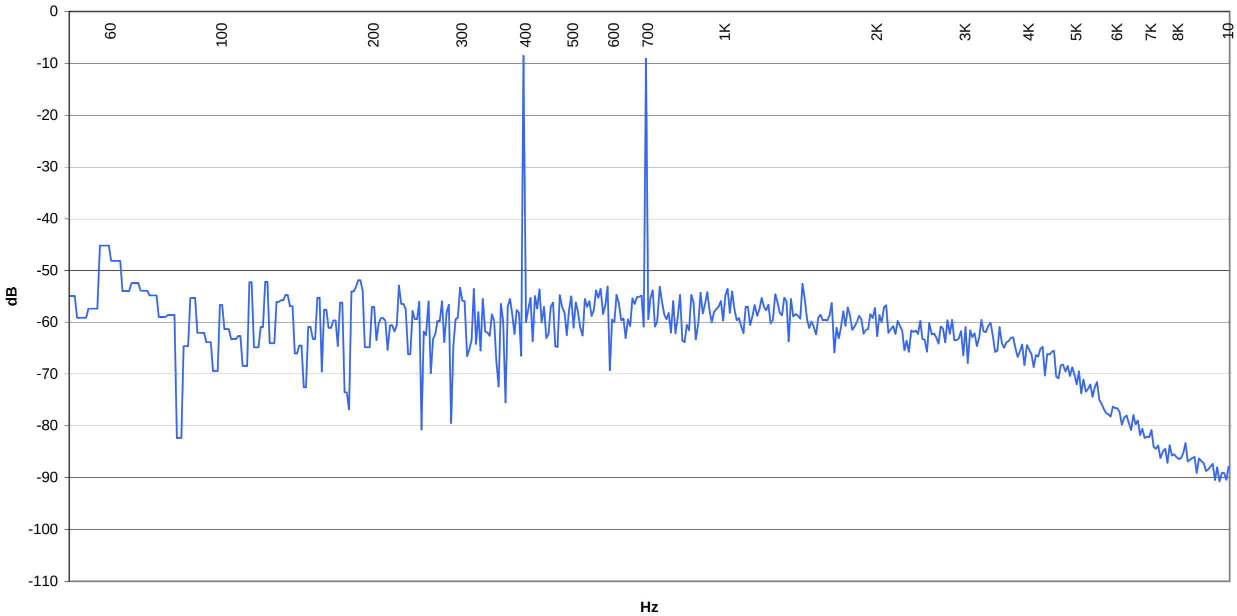
Psophometer-Based Adjacent-Channel Interference

LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	47	32	22	17
-10	47	34	26	22
7	-	40	28	29
-7	-	45	37	31
6	-	40	36	26
-6	-	47	43	37
5	-	44	38	31
-5	-	47	46	41

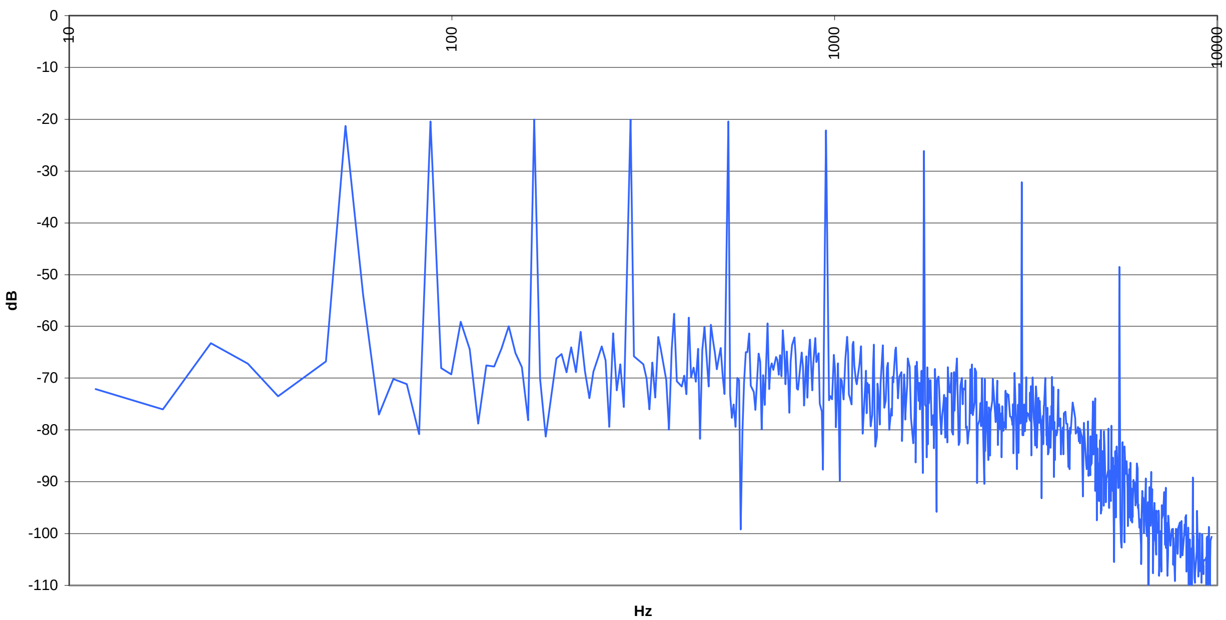
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



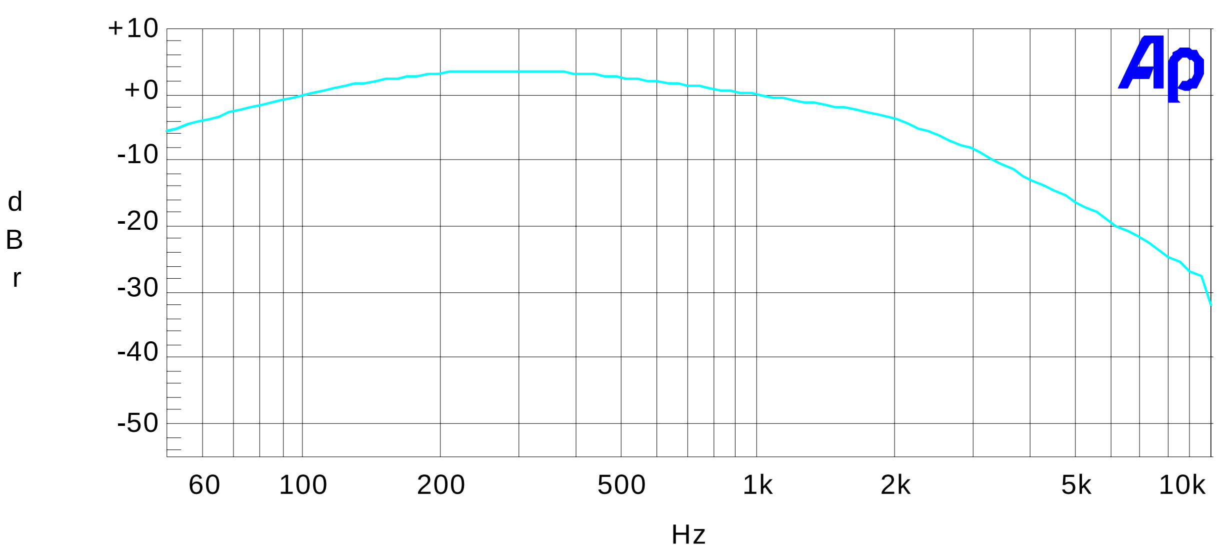
4.3.3 Panasonic RX-FS430A

Category	Portable CD Boom box
AGC Threshold (dBm)	-60
RF Overload (dBm)	-20
RF Test level (dBm)	-40
SNR, unweighted (dB)	40
THD, 400 Hz (%)	0.7
THD, 50 Hz (%)	3.8
SNR, CCIR (dB)	-40
-3 dB Frequency (Hz)	1800
-10 dB Frequency (Hz)	3400

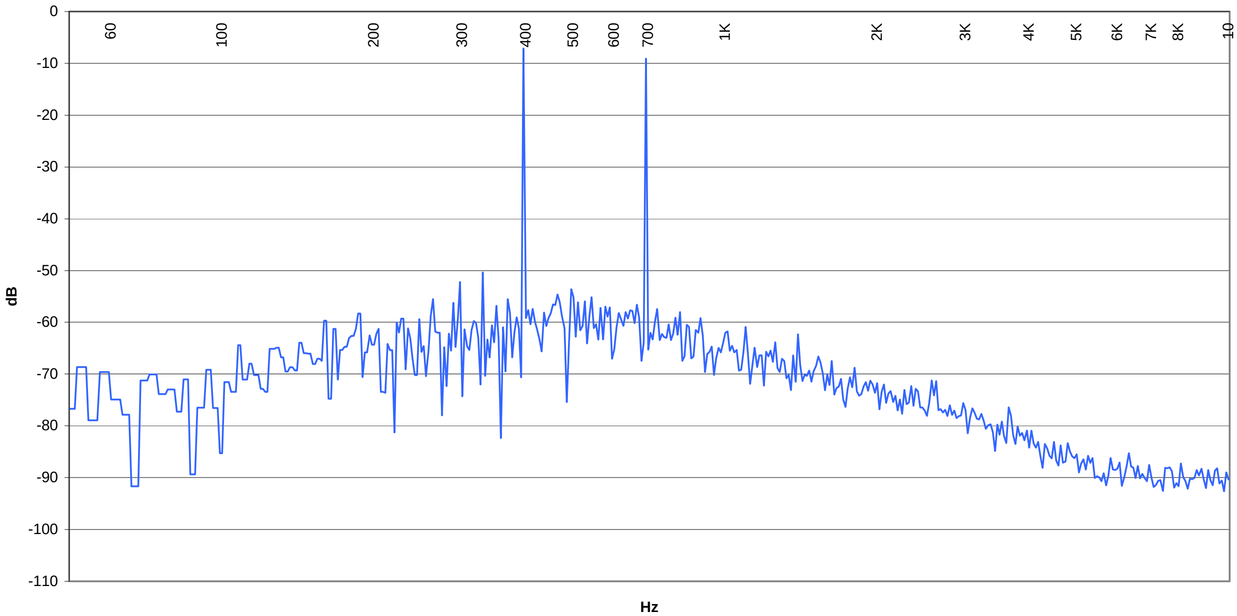
Psophometer-Based Adjacent-Channel Interference

LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	40	34	18	22
-10	35	31	22	20
7	39	40	28	26
-7	39	36	20	19
6	40	40	31	30
-6	38	36	23	20
5	40	40	33	32
-5	39	36	23	22

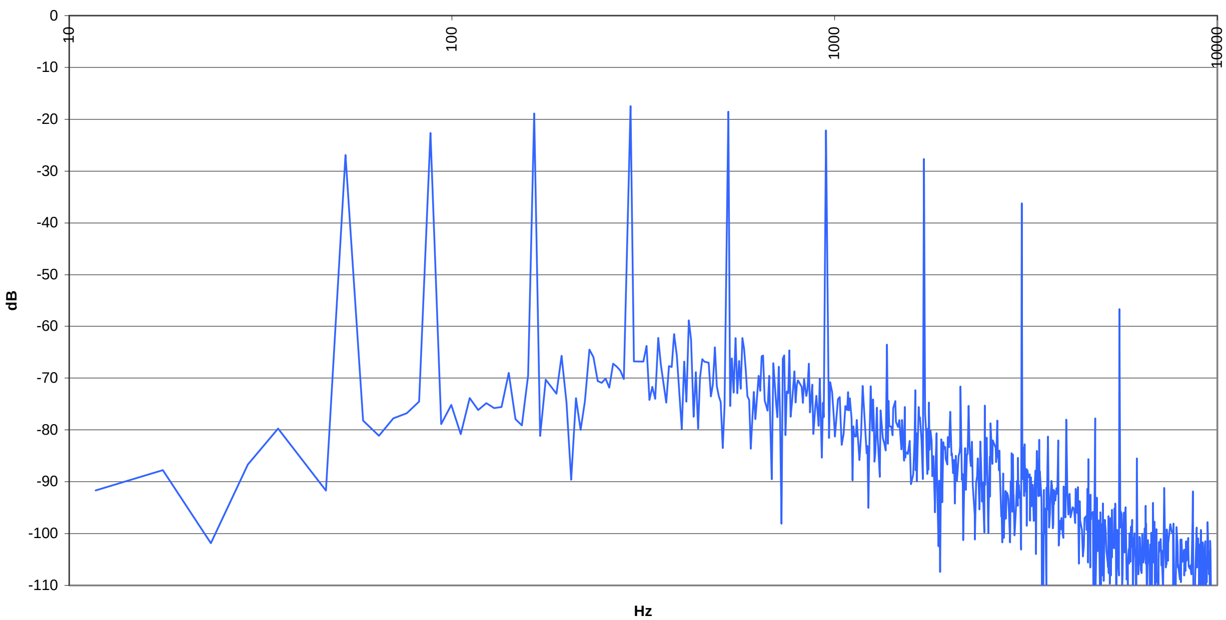
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



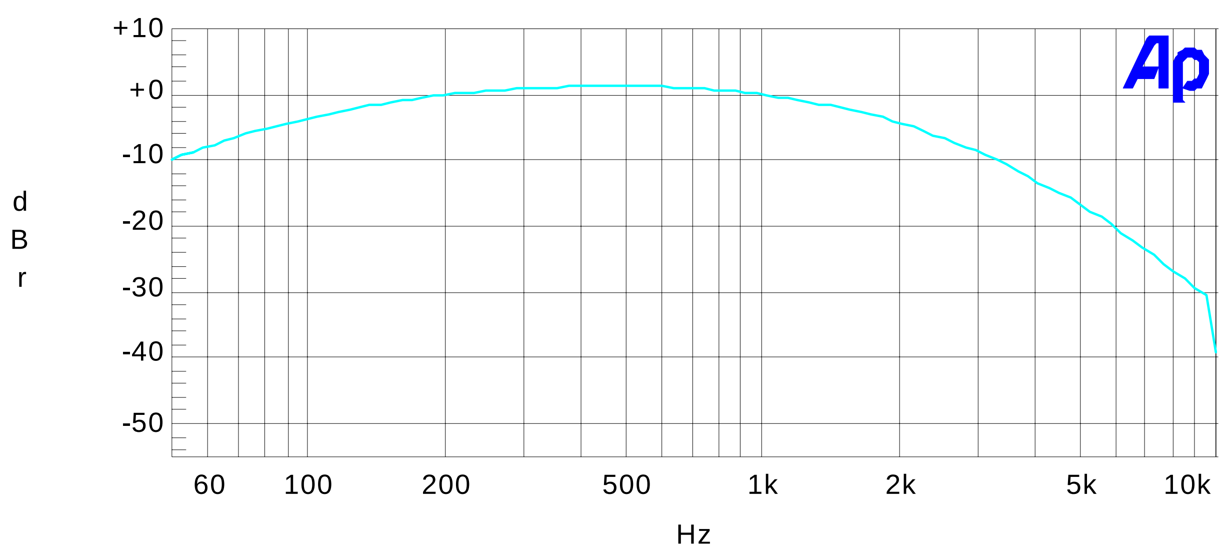
4.3.4 Aiwa JAX-S77

Category	Portable CD Boom box
AGC Threshold (dBm)	-85
RF Overload (dBm)	-10
RF Test level (dBm)	-50
SNR, unweighted (dB)	47
THD, 400 Hz (%)	0.7
THD, 50 Hz (%)	0.8
SNR, CCIR (dB)	-47
-3 dB Frequency (Hz)	1700
-10 dB Frequency (Hz)	3300

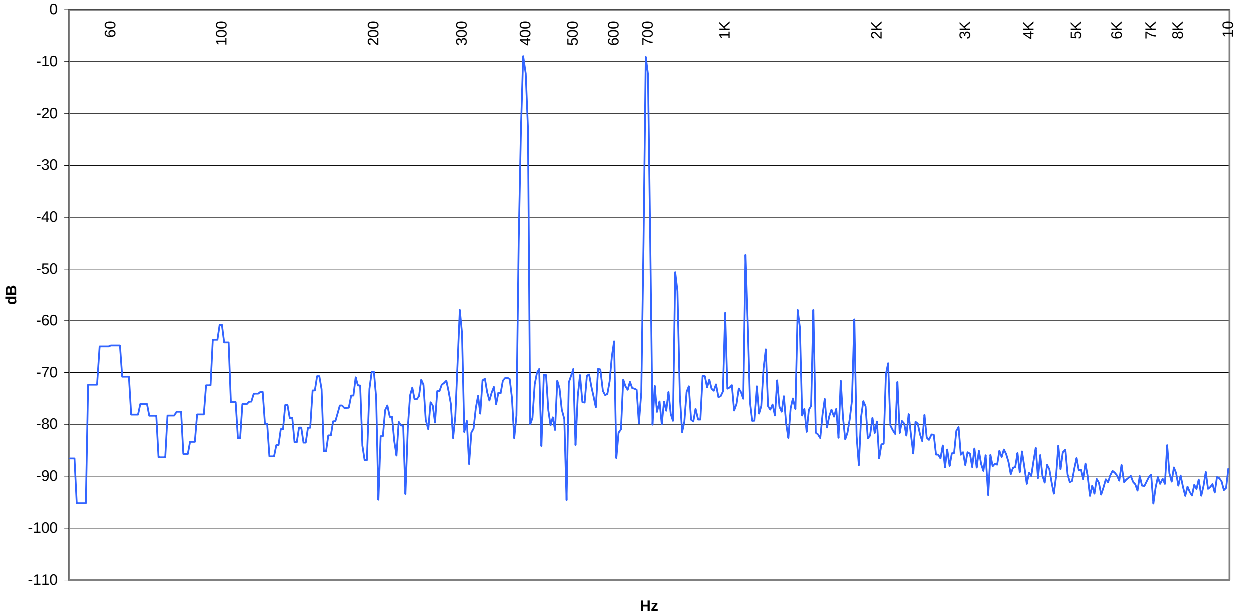
Psophometer-Based Adjacent-Channel Interference

LPF kHz	**D/U (dB)**			
	+30	+15	+6	0
10	47	37	28	23
-10	47	33	23	17
7	-	41	34	27
-7	-	35	27	20
6	-	44	35	29
-6	-	37	30	23
5	-	44	38	32
-5	-	38	30	23

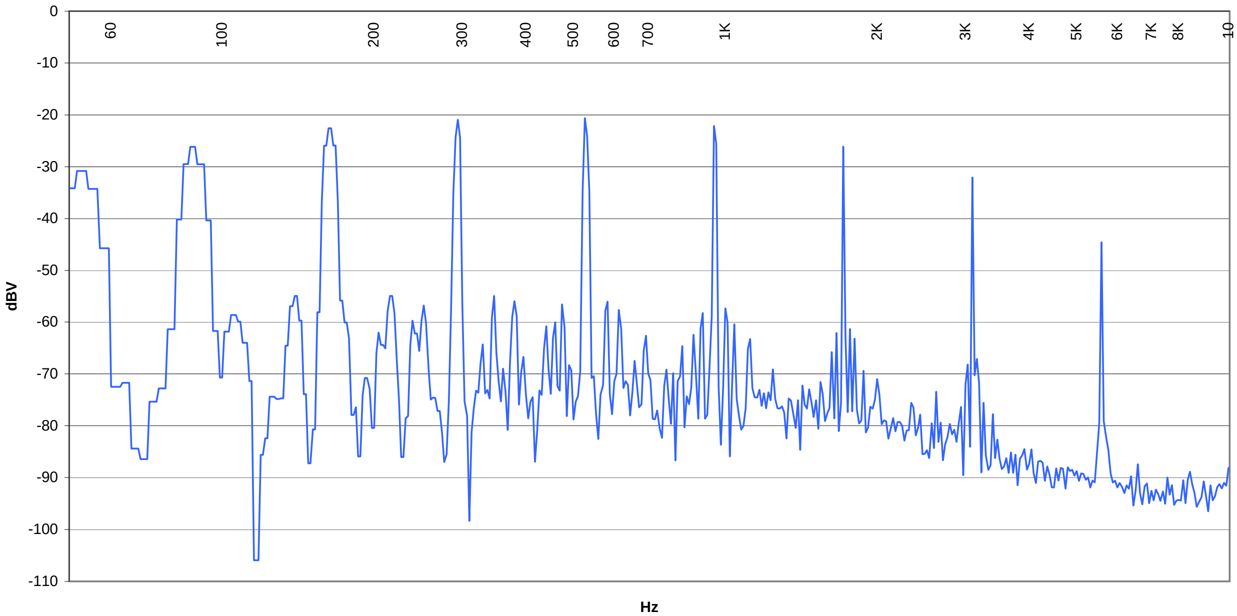
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



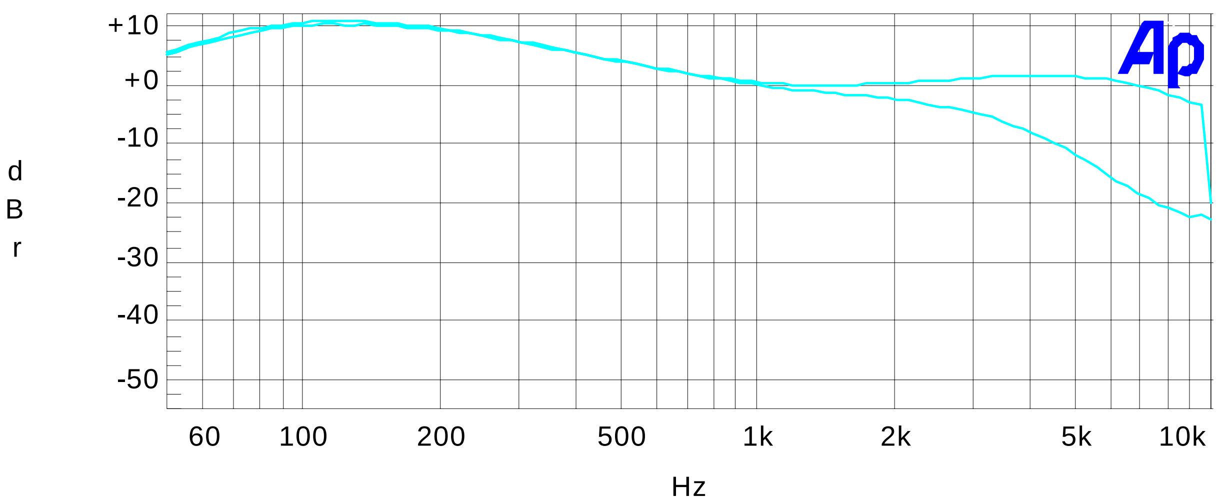
4.3.5 Grundig S350

Category	Portable CD Boom box	
	Narrow Mode	Wide Mode
AGC Threshold (dBm)	-80	-80
RF Overload (dBm)	-35	-35
RF Test level (dBm)	-58	-58
SNR, unweighted (dB)	34	30
THD, 400 Hz (%)	1.5	1.5
THD, 50 Hz (%)	1.4	1.4
SNR, CCIR (dB)	-39	-35
-3 dB Frequency (Hz)	3100	3900
-10 dB Frequency (Hz)	3600	5000

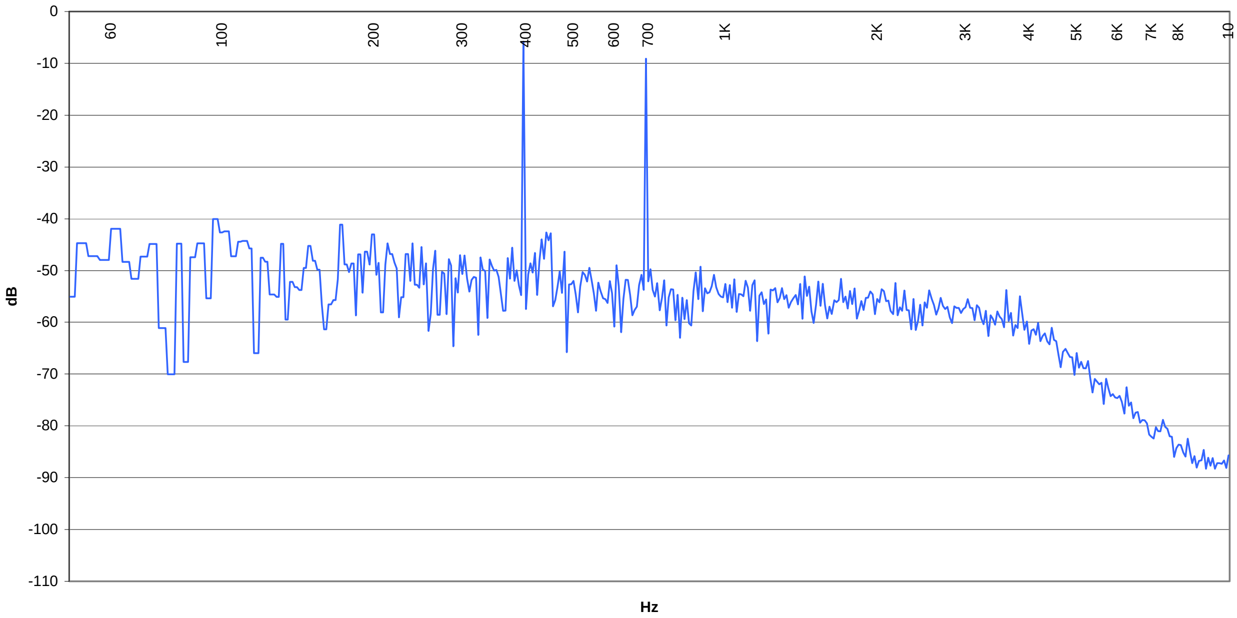
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB) Narrow**					**D/U (dB) Wide**			
	+30	+15	+6	0		+30	+15	+6	0
10	-	32	24	15		34	30	19	14
-10	-	32	22	18		33	22	13	7
7	-	36	28	23		-	32	24	18
-7	-	38	33	28		-	25	16	9
6	-	38	38	32		-	32	27	22
-6	-	39	39	35		-	27	19	14
5	-	39	39	38		-	33	30	24
-5	-	39	39	38		-	30	25	17

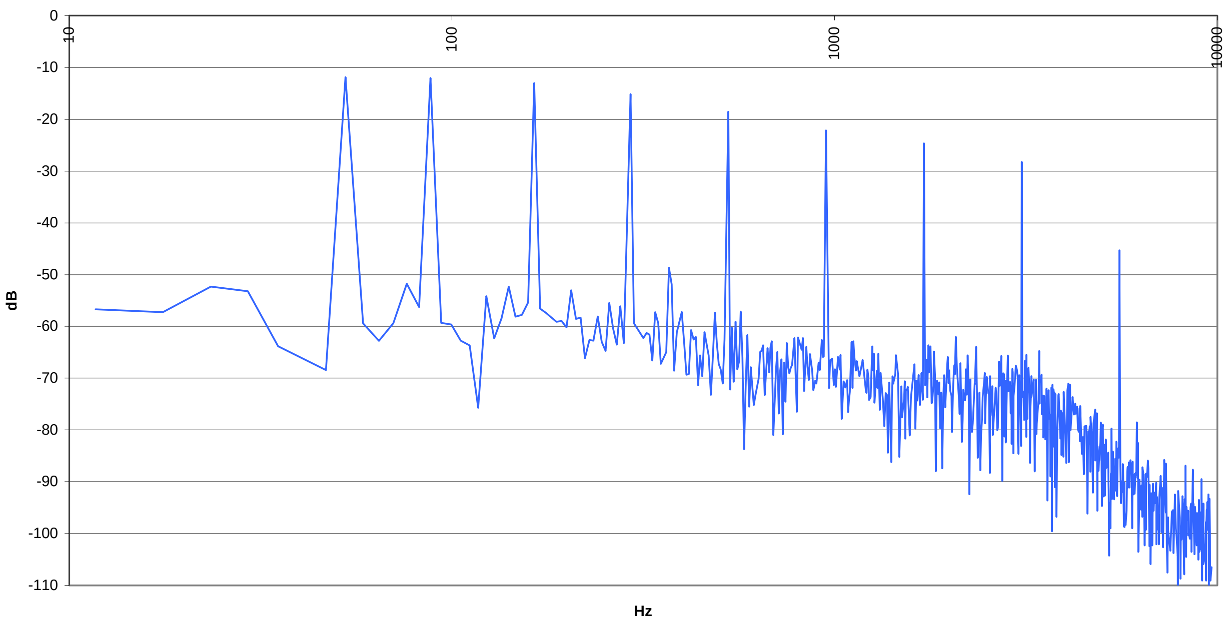
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



4.3.6 GE SuperRadio III

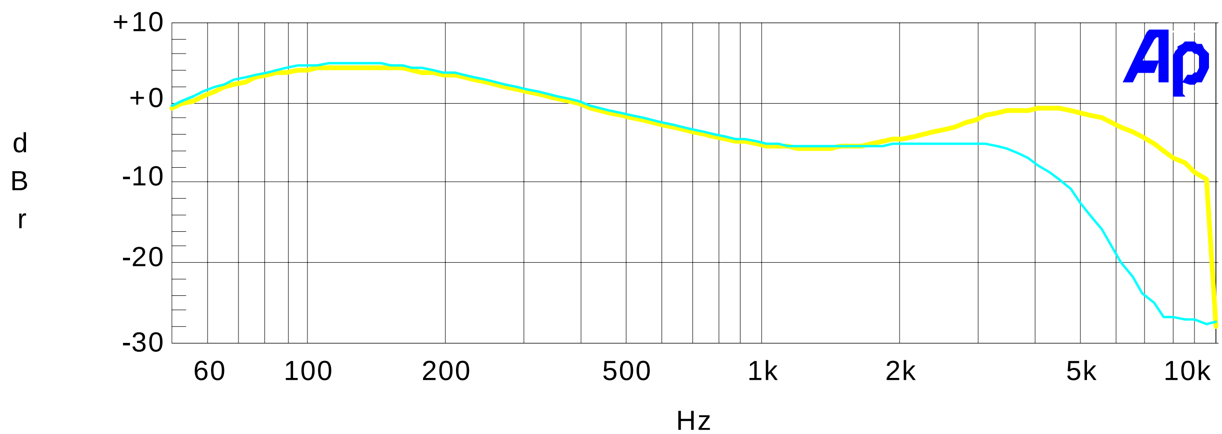
Category	Portable CD Boom box Wide Mode	Narrow Mode
AGC Threshold (dBm)	-40	-40
RF Overload (dBm)	-80	-80
RF Test level (dBm)	-60	-60
SNR, unweighted (dB)	31	28
THD, 400 Hz (%)	3.2	3.9
THD, 50 Hz (%)	14	10
SNR, CCIR (dB)	-34	-34
-3 dB Frequency (Hz)	2900*	4100
-10 dB Frequency (Hz)	9600*	5500

*Upper response hump

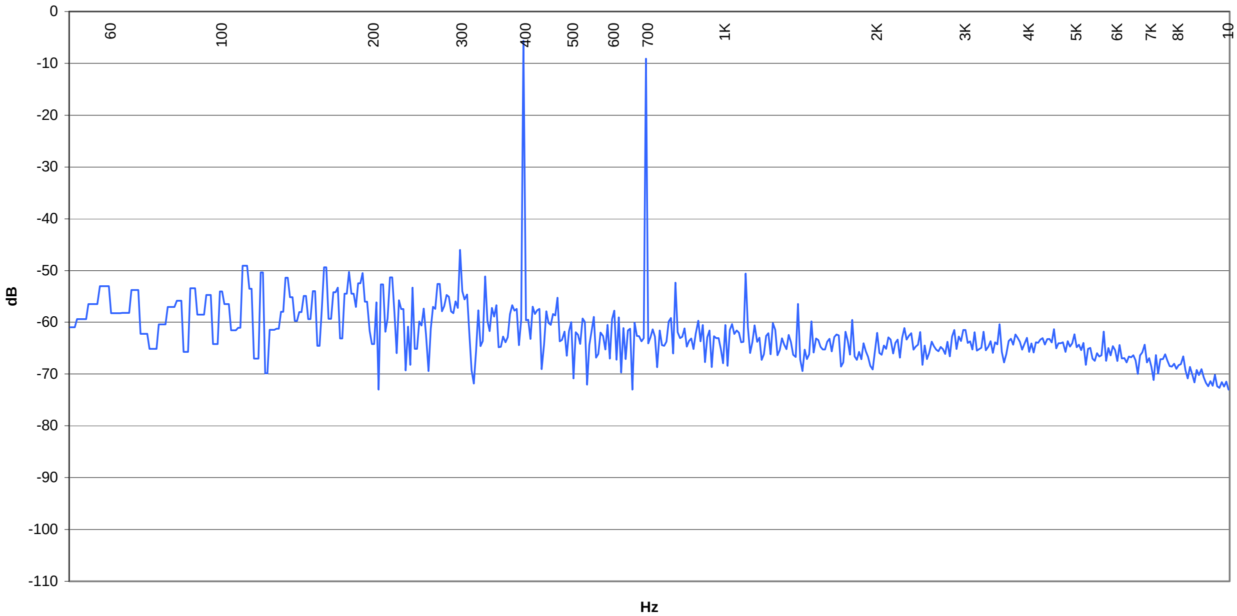
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB) Wide**				**D/U (dB) Narrow**			
	+30	+15	+6	0	+30	+15	+6	0
10	28	13	6	0	-	30	23	17
-10	30	18	10	3	-	29	20	15
7	24	14	6	1	-	34	28	20
-7	31	19	10	4	-	32	24	17
6	28	15	6	1	-	36	30	26
-6	31	17	10	3	-	33	24	20
5	28	14	6	1	-	36	34	29
-5	31	18	10	4	-	34	28	22

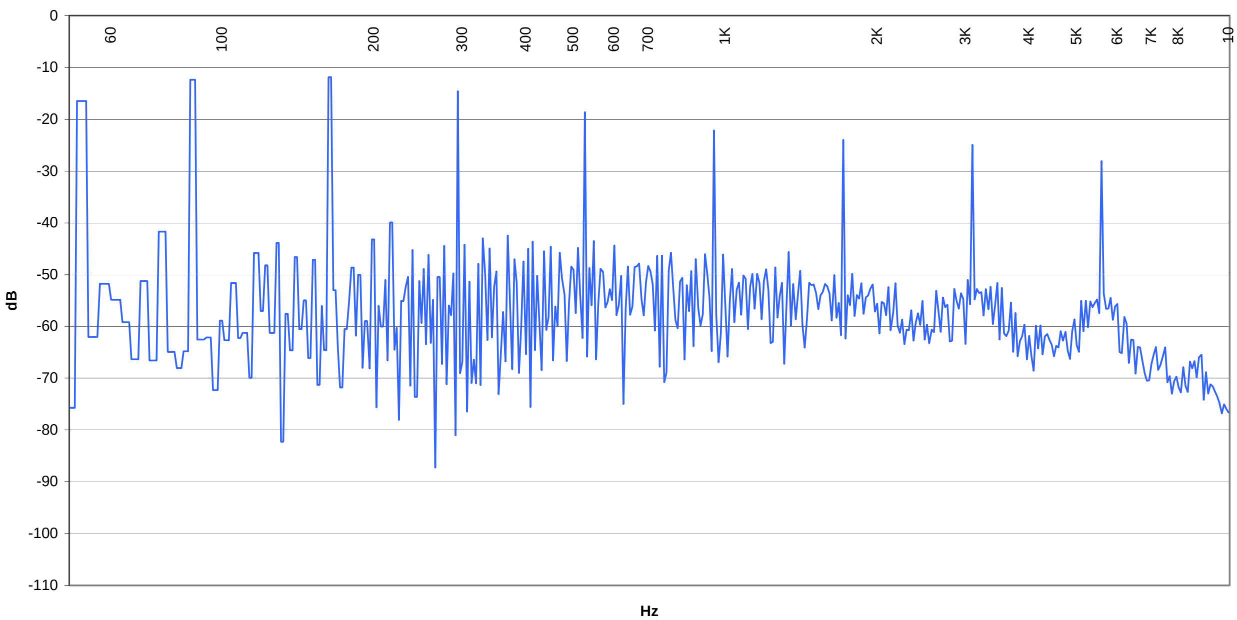
Measurement of AM Frequency Responses at Wide and Narrow Bandwidth



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



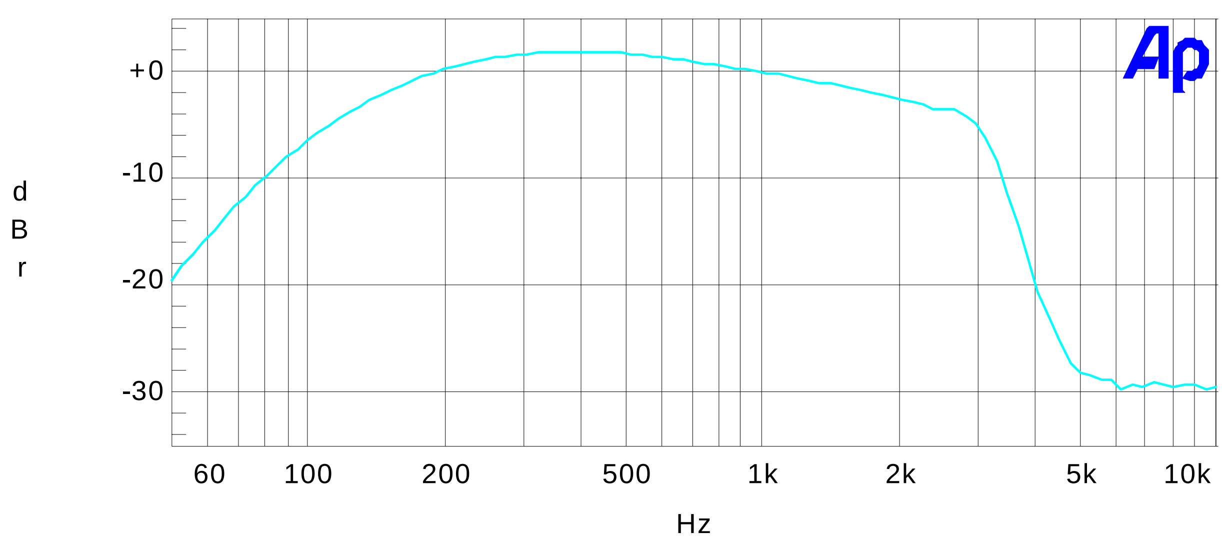
4.3.7 Crane CCRadio Plus

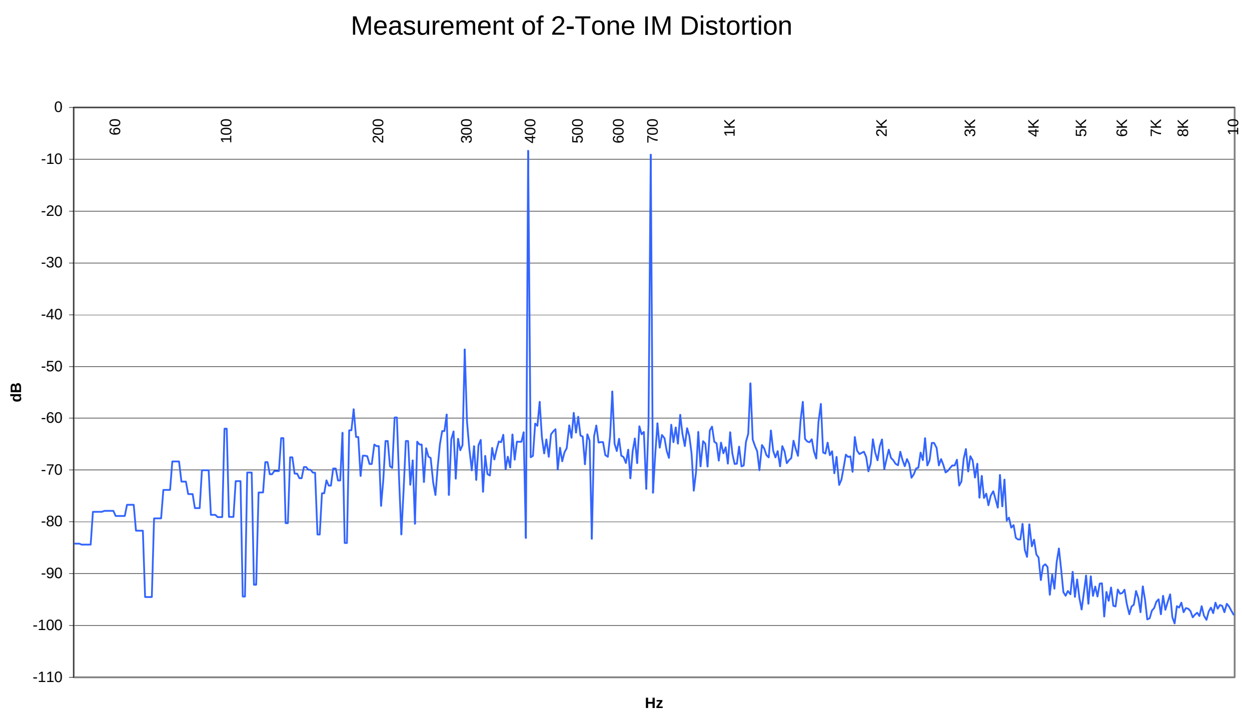
Category	Portable CD Boom box
AGC Threshold (dBm)	-70
RF Overload (dBm)	-20
RF Test level (dBm)	-45
SNR, unweighted (dB)	44.4
THD, 400 Hz (%)	3.45
THD, 50 Hz (%)	none
SNR, CCIR (dB)	-29
-3 dB Frequency (Hz)	3200
-10 dB Frequency (Hz)	3600

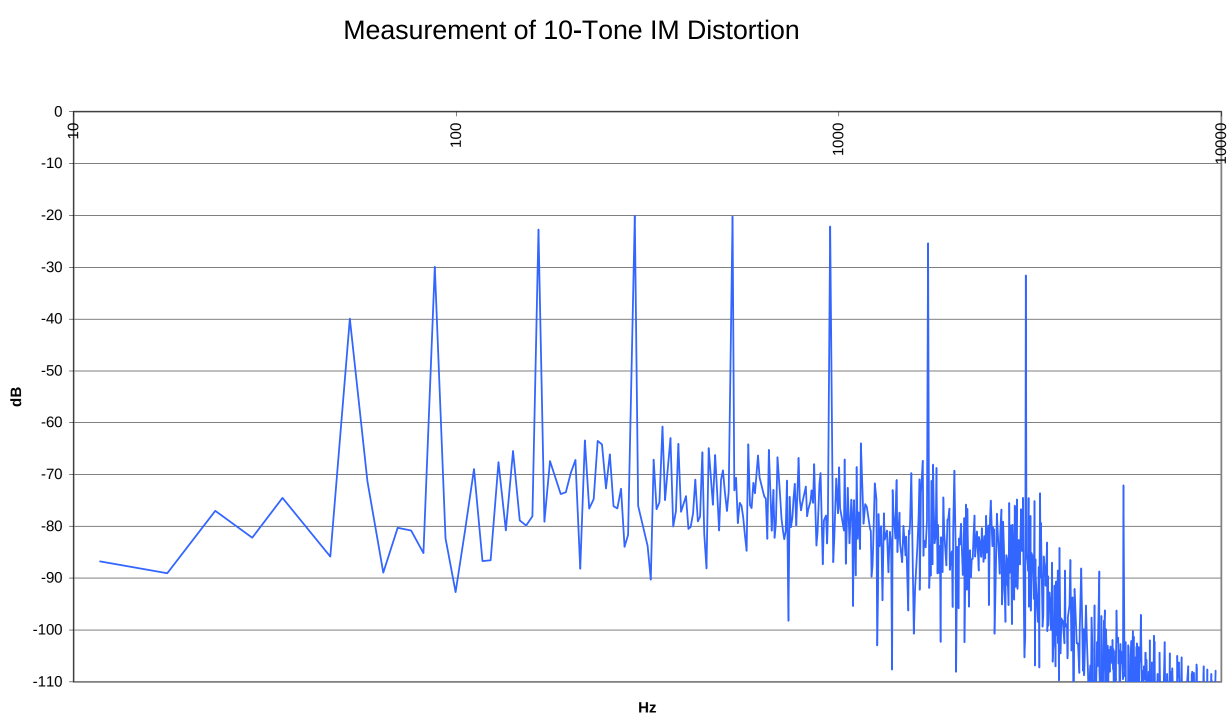
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	-	23	14	8
-10	-	22	15	10
7	-	28	23	17
-7	-	27	23	18
6	-	29	28	25
-6	-	29	28	26
5	-	29	29	28
-5	-	29	29	28

Measurement of AM Frequency Response




Measurement of 2-Tone IM Distortion
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
dB
60
100
200
300
400
500
600
700
1K
2K
3K
4K
5K
6K
7K
8K
10
Hz


Measurement of 10-Tone IM Distortion
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
dB
10
100
1000
10000
Hz

4.4 Car In-Dash Radios

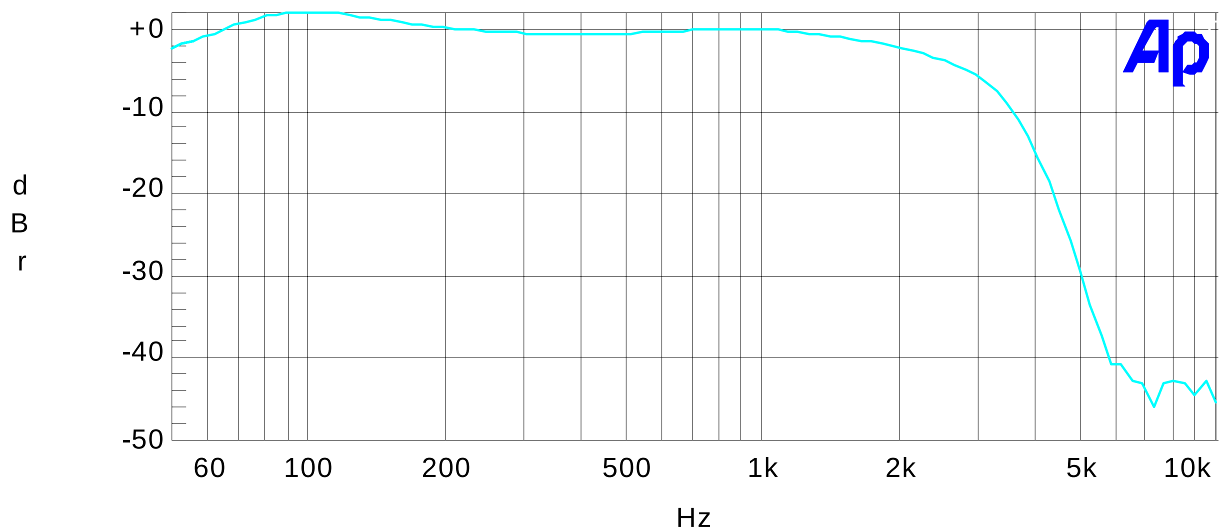
4.4.1 Pioneer DEH-P6600

Category	Car in-dash CD
AGC Threshold (dBm)	-95
RF Overload (dBm)	>0
RF Test level (dBm)	-65
SNR, unweighted (dB)	57
THD, 400 Hz (%)	1.1
THD, 50 Hz (%)	1.2
SNR, CCIR (dB)	-51
-3 dB Frequency (Hz)	2200
-10 dB Frequency (Hz)	3600

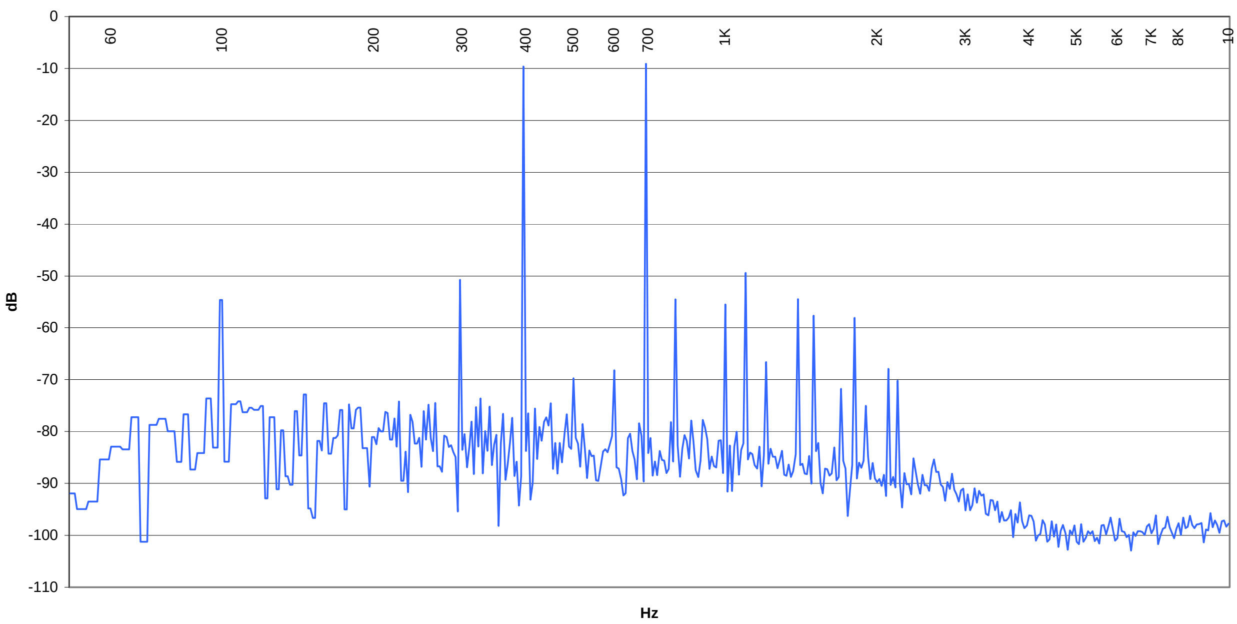
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	45	30	21	16
-10	44	30	21	15
7	49	39	30	24
-7	49	38	28	22
6	50	47	39	32
-6	50	45	37	30
5	50	49	46	38
-5	50	49	44	37

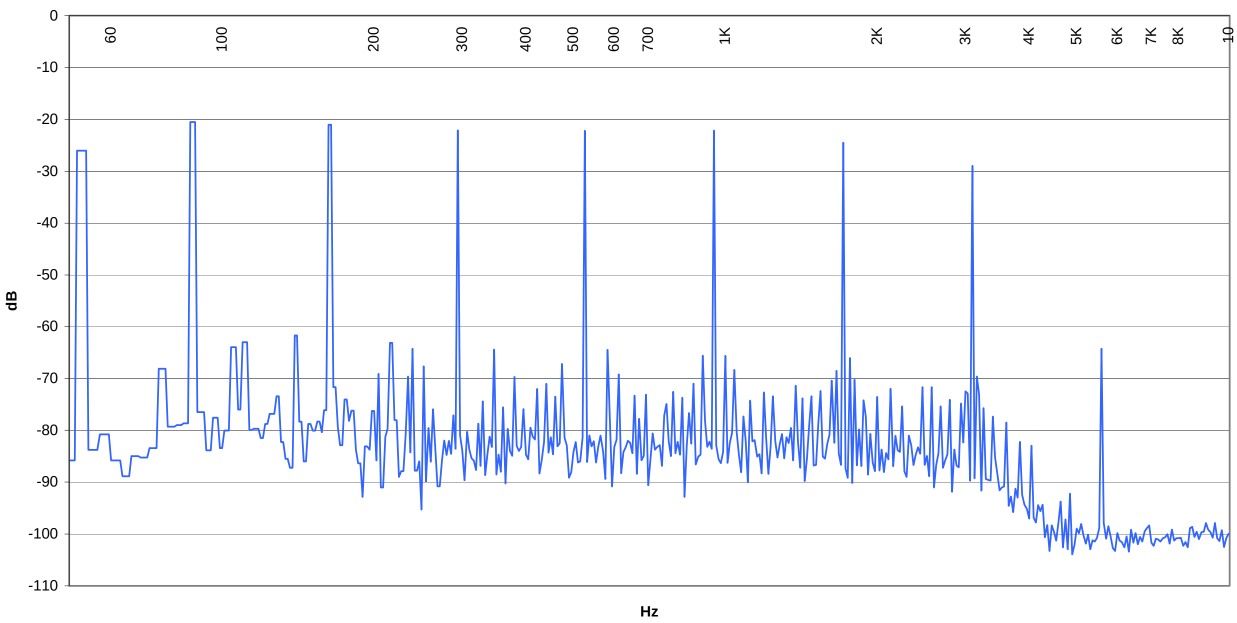
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



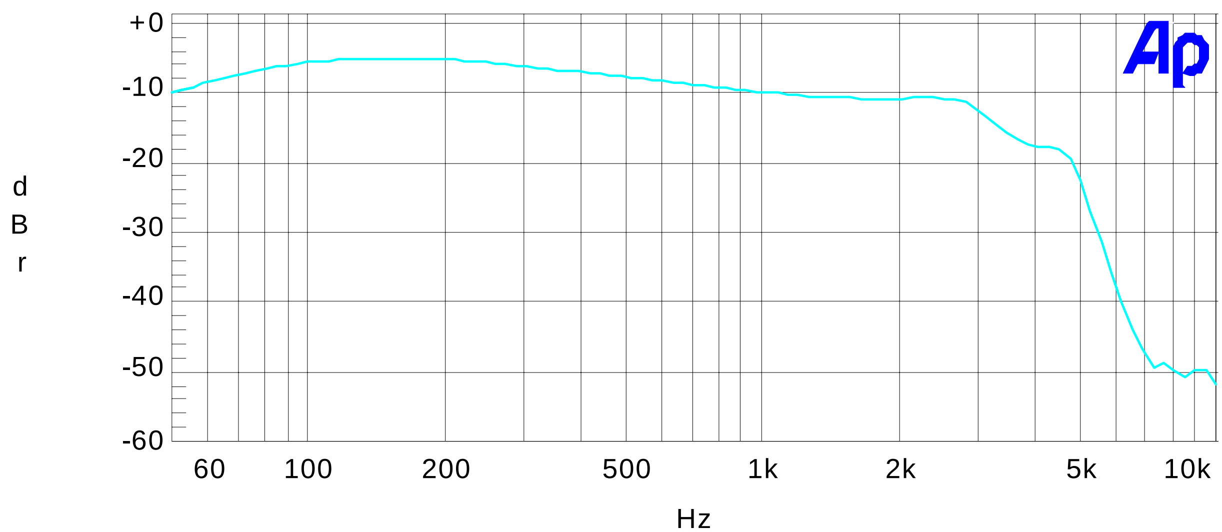
4.4.2 Kenwood KDC-3025

Category	Car in-dash CD
AGC Threshold (dBm)	-100
RF Overload (dBm)	-5
RF Test level (dBm)	-50
SNR, unweighted (dB)	53
THD, 400 Hz (%)	0.6
THD, 50 Hz (%)	0.7
SNR, CCIR (dB)	-49
-3 dB Frequency (Hz)	3100
-10 dB Frequency (Hz)	4800

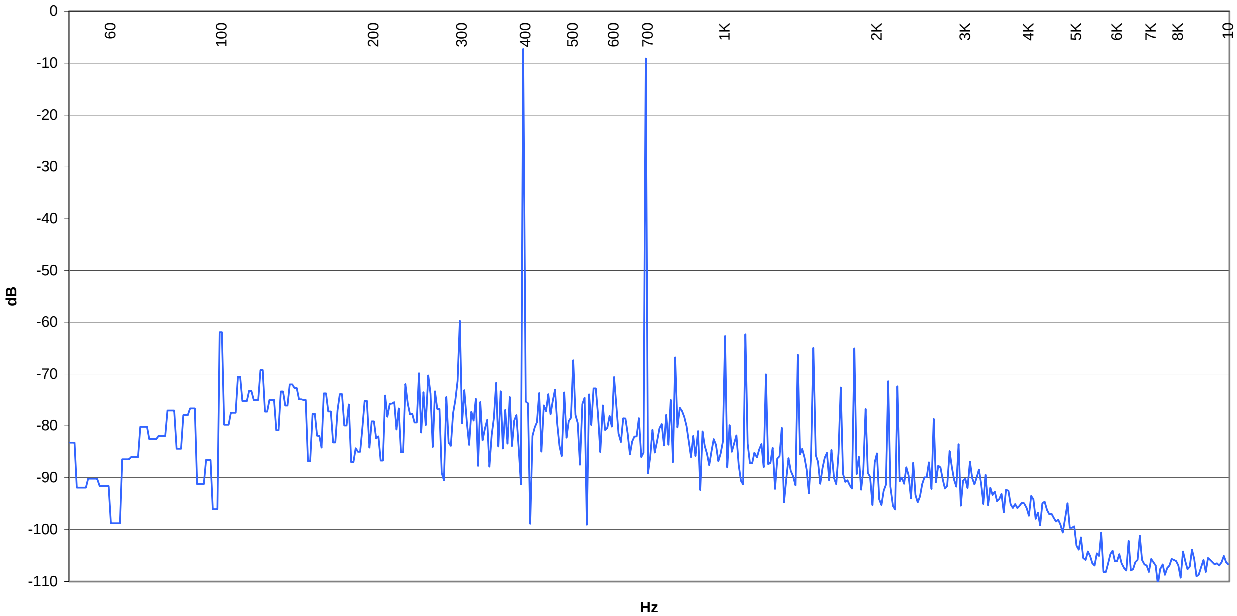
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	42	28	27	27
-10	44	29	29	29
7	45	29	29	29
-7	48	33	33	33
6	47	31	31	31
-6	49	35	35	34
5	49	33	33	32
-5	49	36	36	35

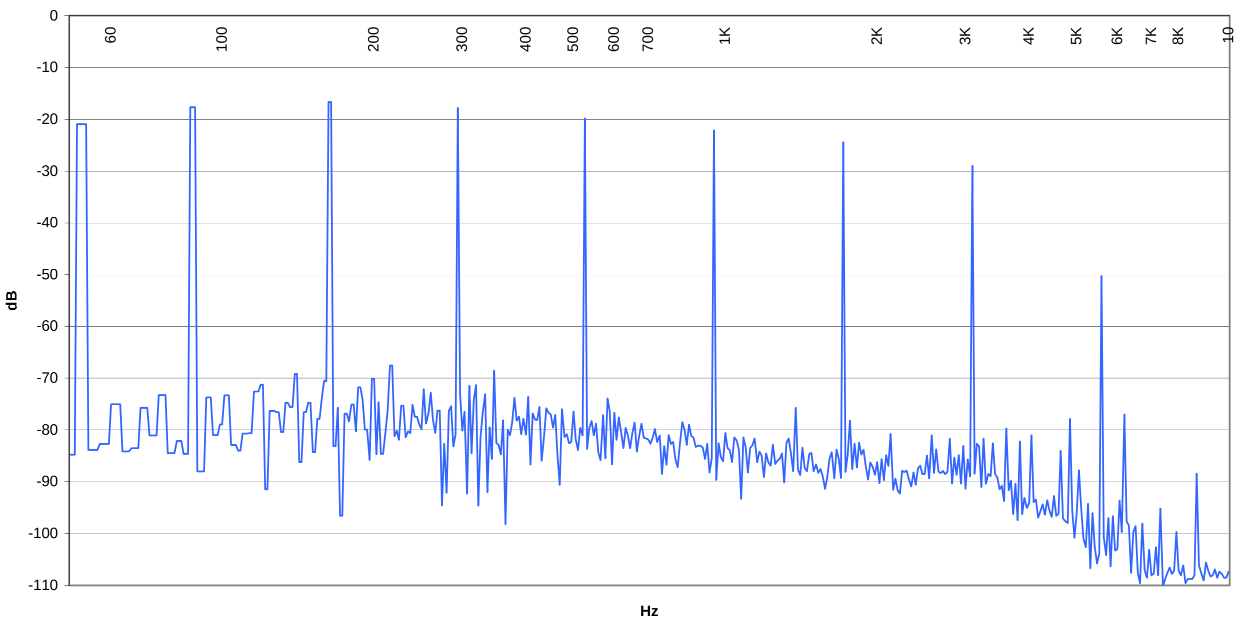
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



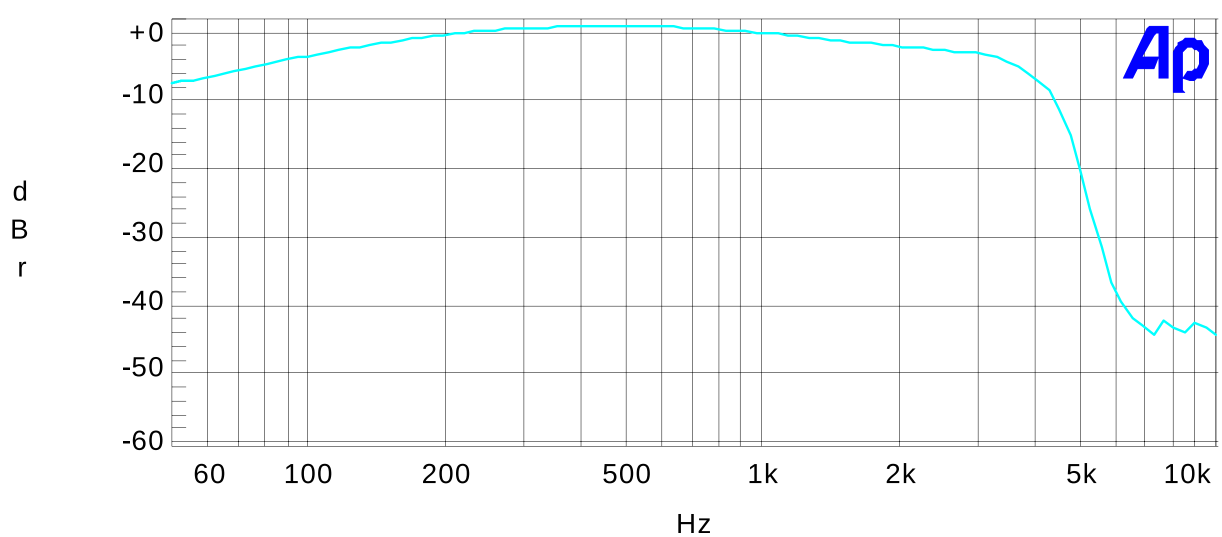
4.4.3 Sony XR-F5100X

Category	Car in-dash cassette
AGC Threshold (dBm)	-90
RF Overload (dBm)	0
RF Test level (dBm)	-45
SNR, unweighted (dB)	57
THD, 400 Hz (%)	0.8
THD, 50 Hz (%)	0.9
SNR, CCIR (dB)	-52
-3 dB Frequency (Hz)	3000
-10 dB Frequency (Hz)	4400

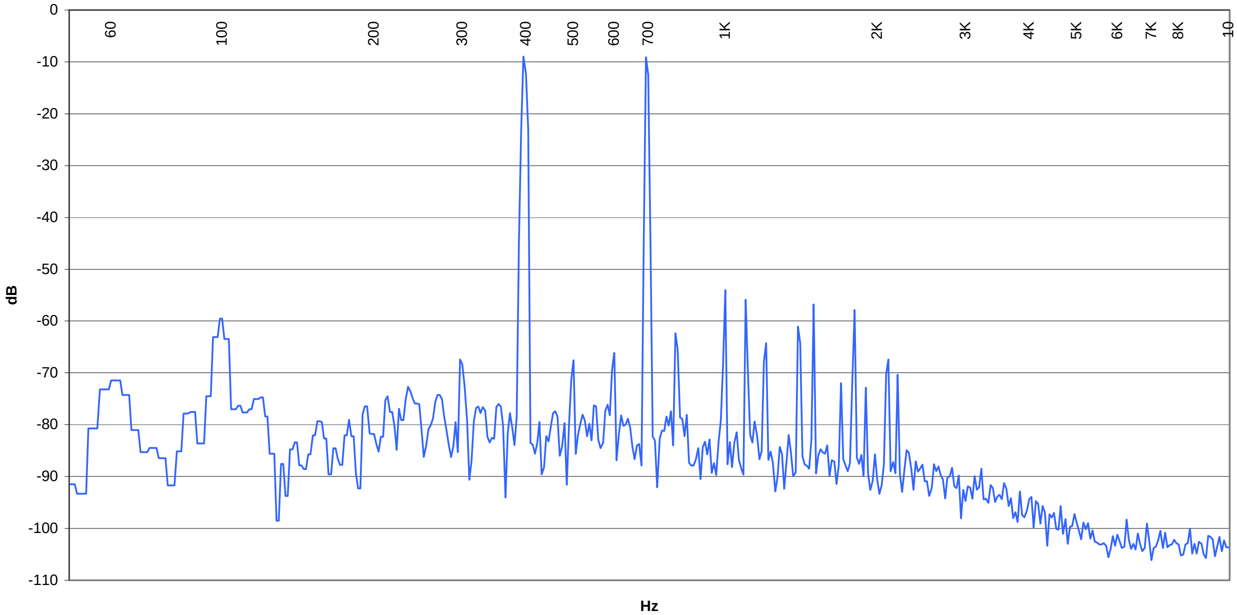
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	45	30	21	16
-10	44	30	21	14
7	50	36	28	22
-7	49	35	26	20
6	52	43	34	28
-6	51	41	32	26
5	52	51	44	37
-5	52	50	43	35

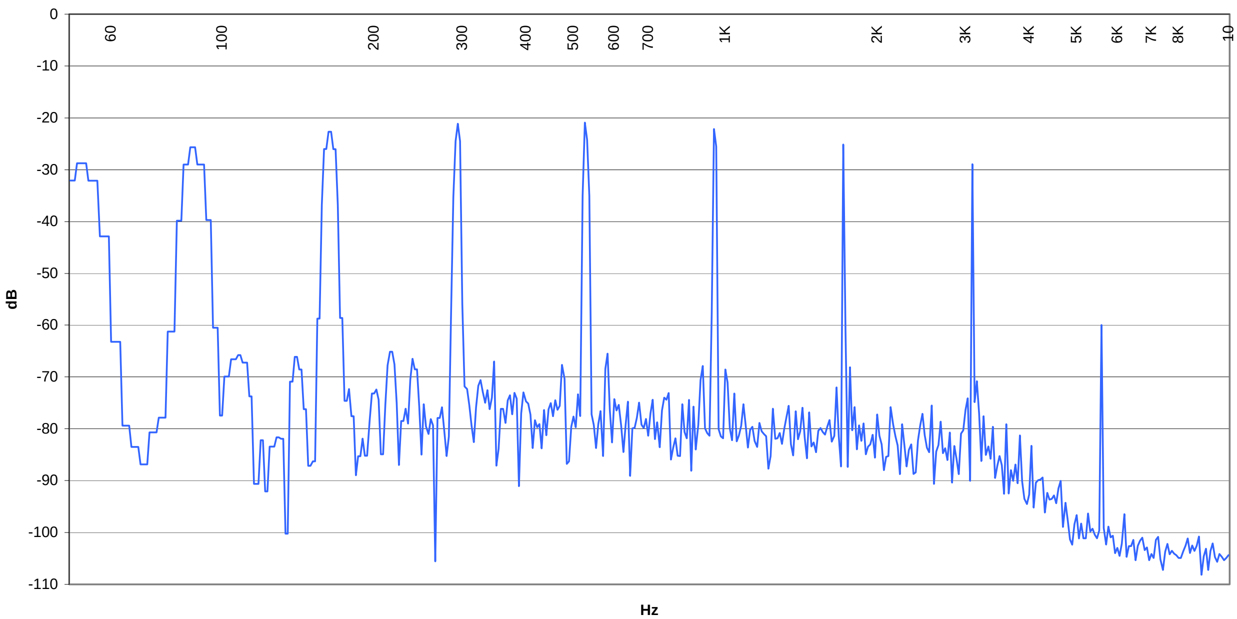
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of Multi-Tone IM Distortion



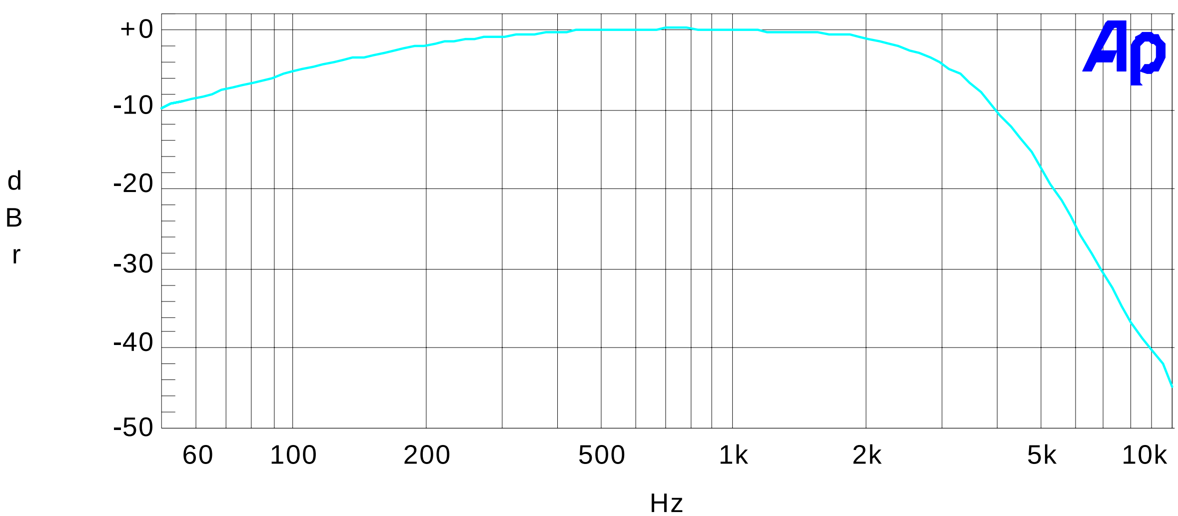
4.4.4 JVC KS-FX490

Category	Car in-dash cassette
AGC Threshold (dBm)	-90
RF Overload (dBm)	-10
RF Test level (dBm)	-50
SNR, unweighted (dB)	56
THD, 400 Hz (%)	0.5
THD, 50 Hz (%)	2
SNR, CCIR (dB)	-50
-3 dB Frequency (Hz)	2600
-10 dB Frequency (Hz)	3900

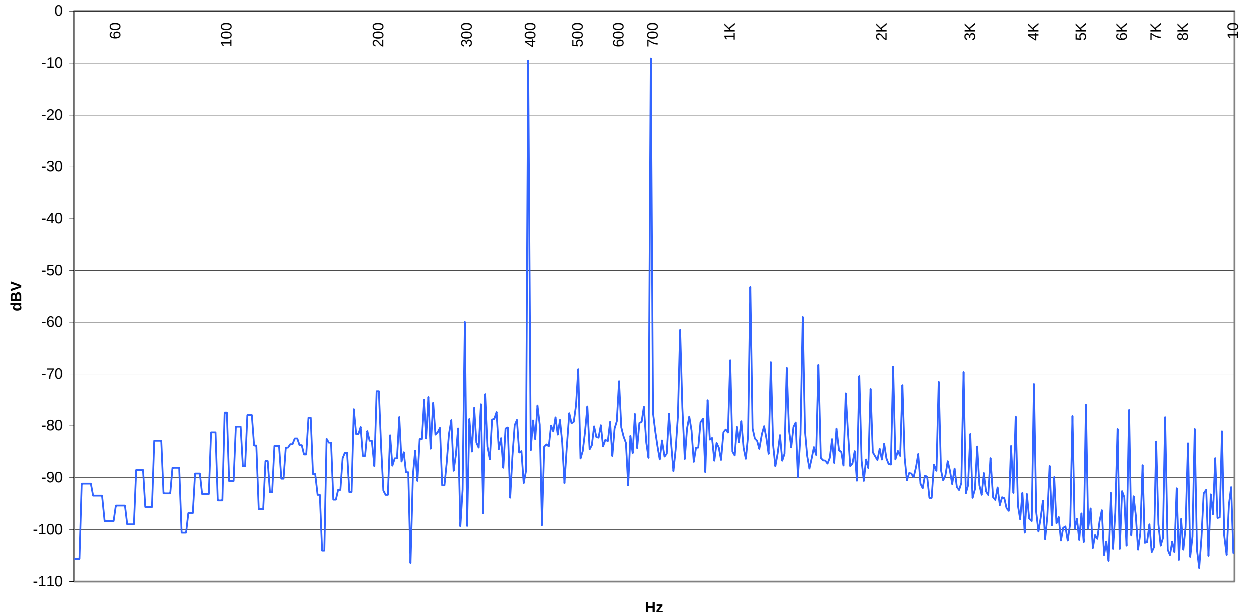
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	44	30	21	15
-10	45	31	22	16
7	48	27	28	22
-7	49	40	31	24
6	49	42	34	27
-6	49	43	35	30
5	49	45	38	32
-5	49	46	40	34

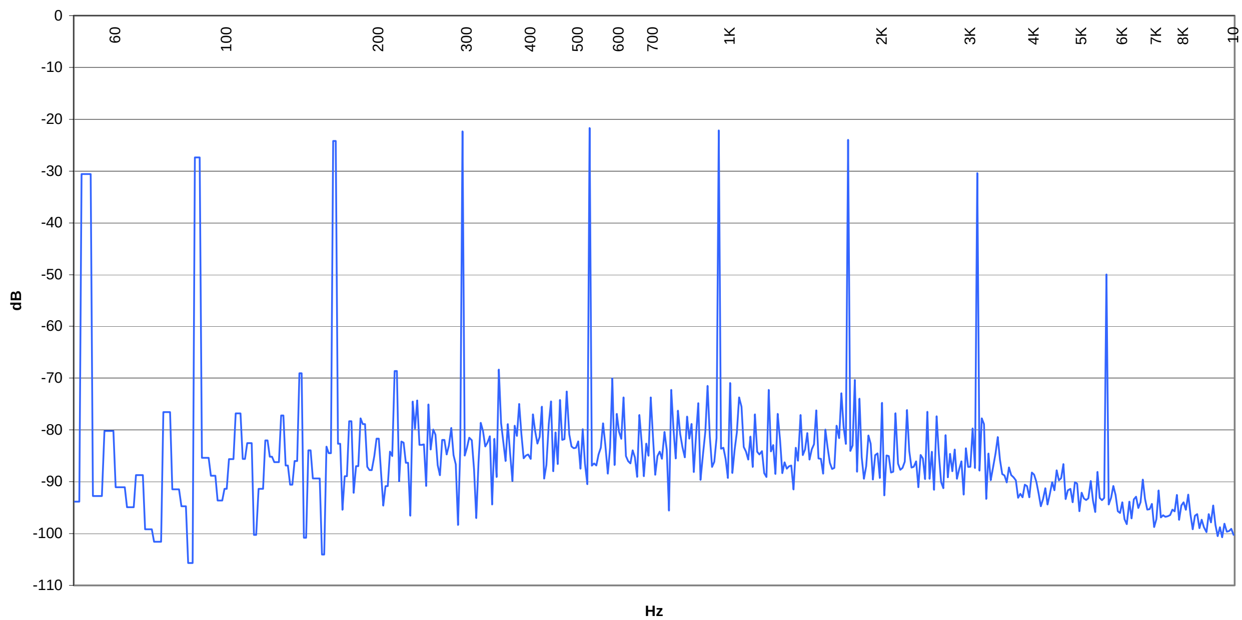
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



4.5 OEM Auto Radios

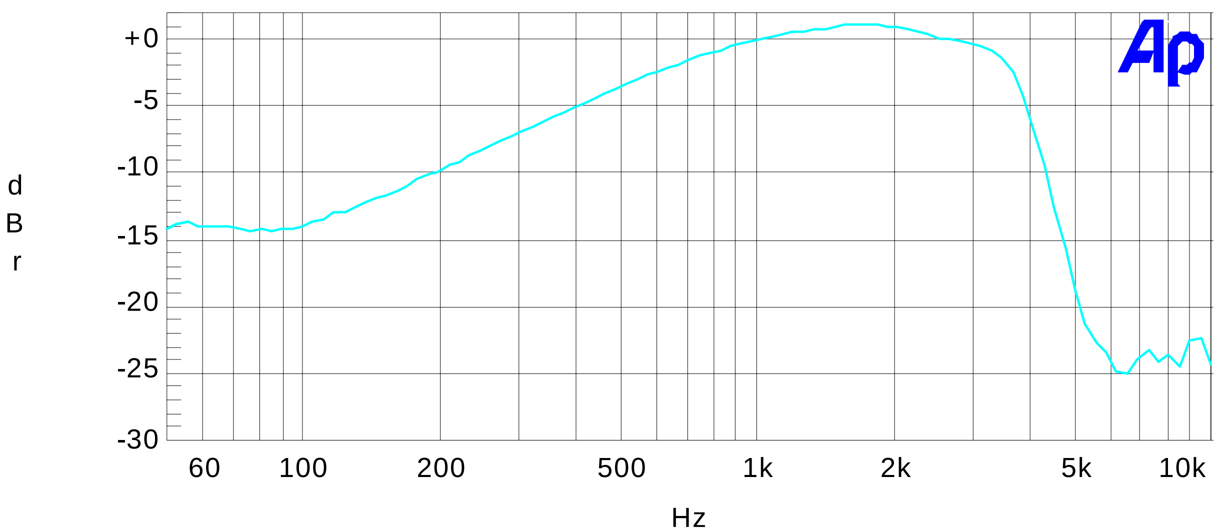
4.5.1 Chevrolet 1995 Camaro

Category	OEM auto
AGC Threshold (dBm)	-115
RF Overload (dBm)	-65
RF Test level (dBm)	-85
SNR, unweighted (dB)	41
THD, 400 Hz (%)	2.3
THD, 50 Hz (%)	2.4
SNR, CCIR (dB)	-31
-3 dB Frequency (Hz)	3700
-10 dB Frequency (Hz)	4300

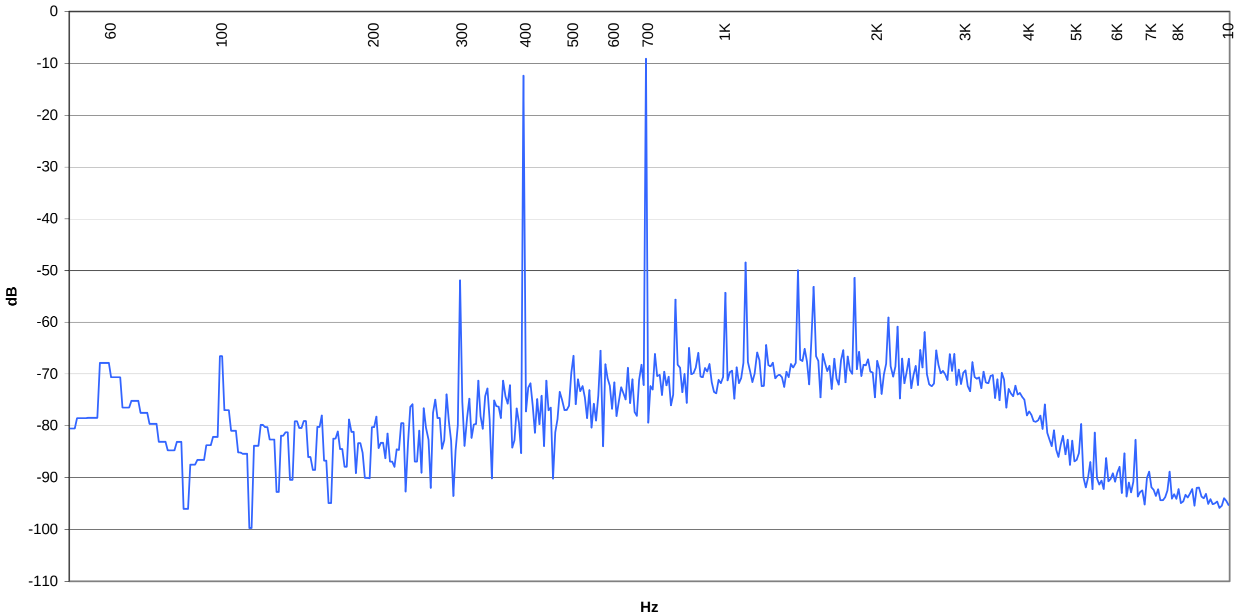
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	D/U (dB)			
	+30	+15	+6	0
10	-	28	16	14
-10	-	28	15	14
7	-	30	18	18
-7	-	30	19	18
6	-	-	26	25
-6	-	-	27	26
5	-	-	30	30
-5	-	-	30	30

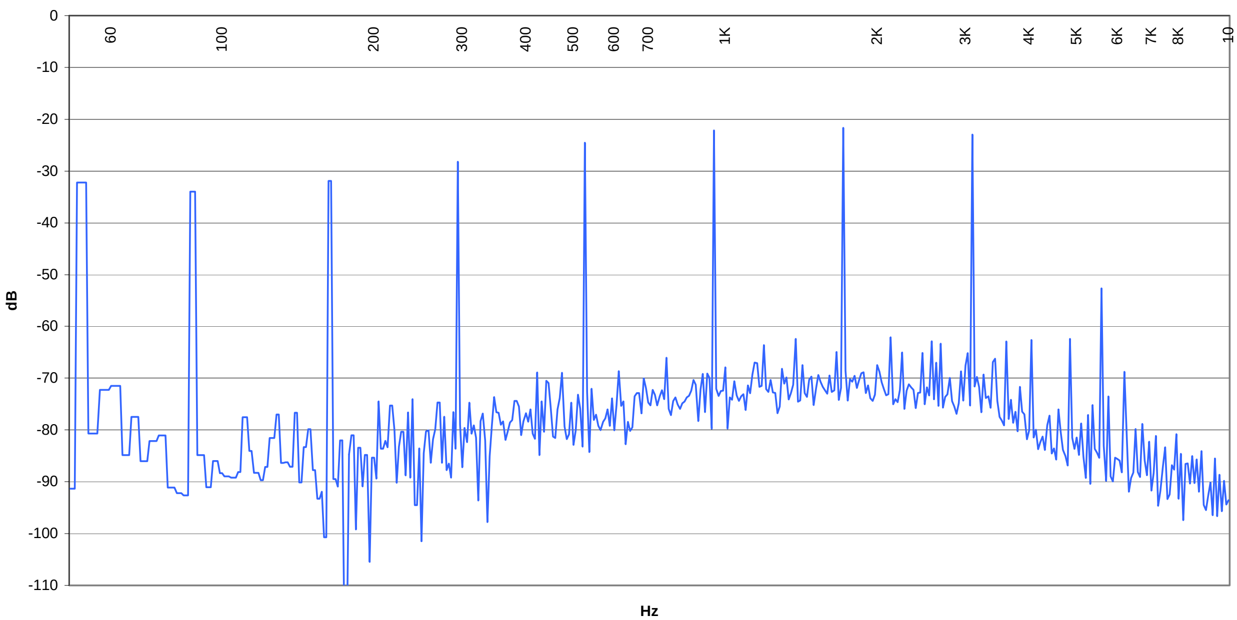
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



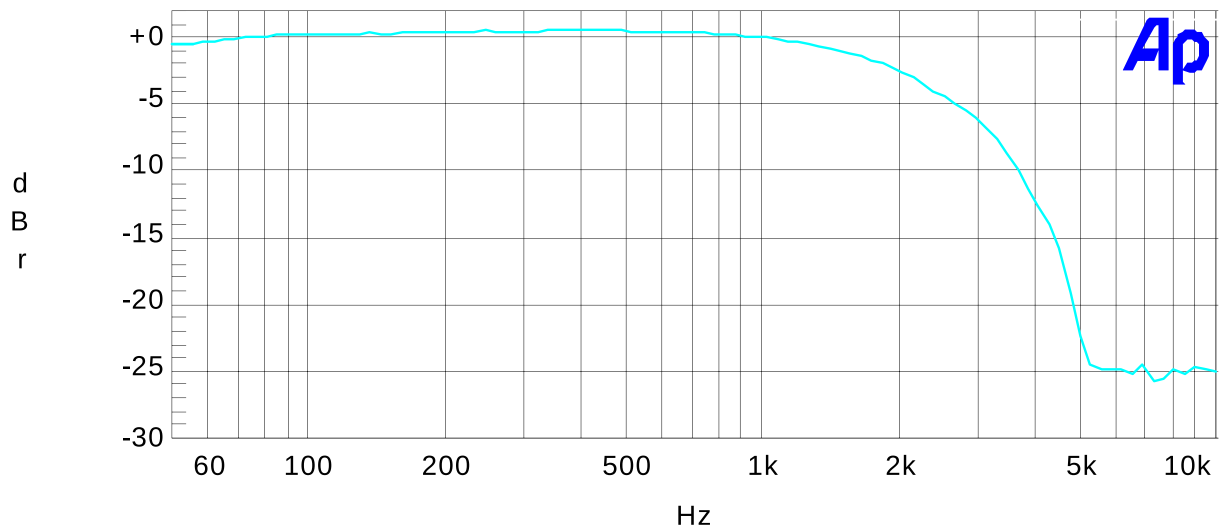
4.5.2 Chevrolet 2000 Tahoe

Category	OEM auto
AGC Threshold (dBm)	-115
RF Overload (dBm)	>0
RF Test level (dBm)	-85
SNR, unweighted (dB)	-40
THD, 400 Hz (%)	1.7
THD, 50 Hz (%)	1.4
SNR, CCIR (dB)	-33
-3 dB Frequency (Hz)	2800
-10 dB Frequency (Hz)	4200

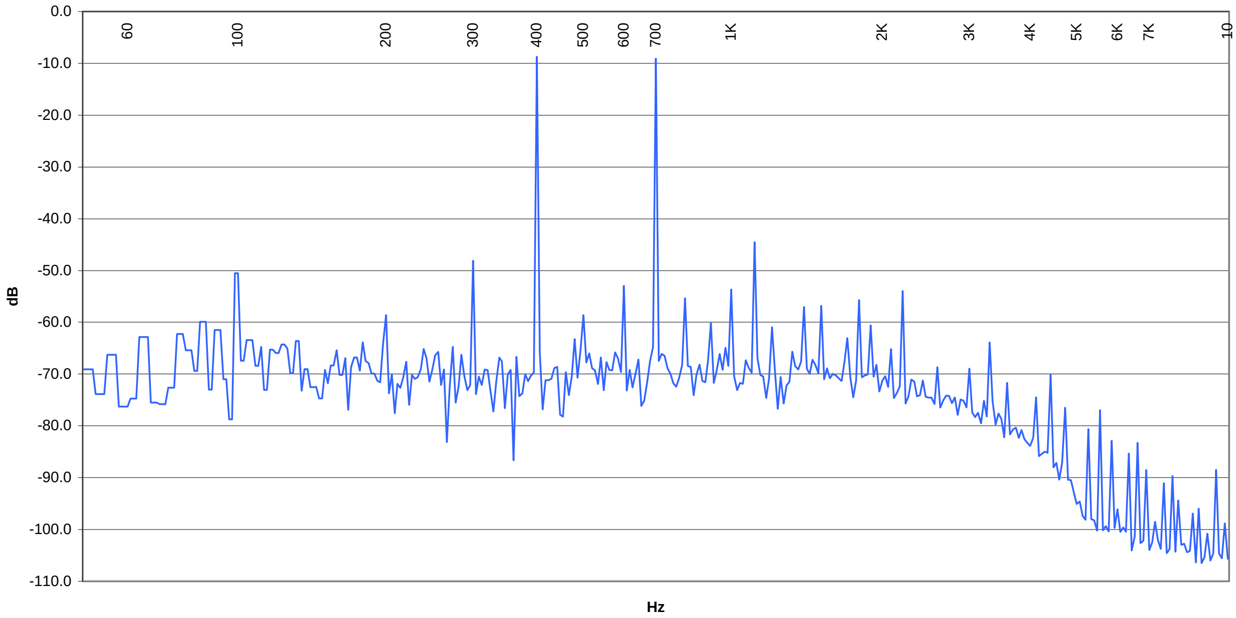
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	D/U (dB)			
	+30	+15	+6	0
10	-	29	23	18
-10	-	30	23	22
7	-	-	29	25
-7	-	-	28	29
6	-	-	31	30
-6	-	-	31	29
5	-	-	-	32
-5	-	-	-	32

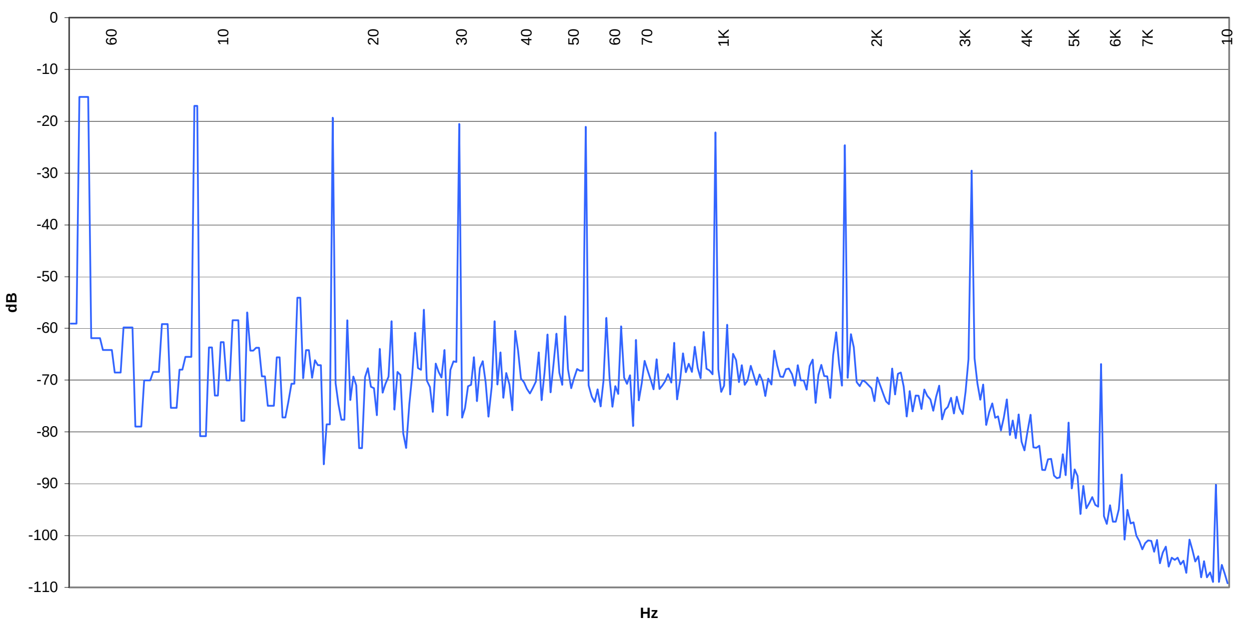
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



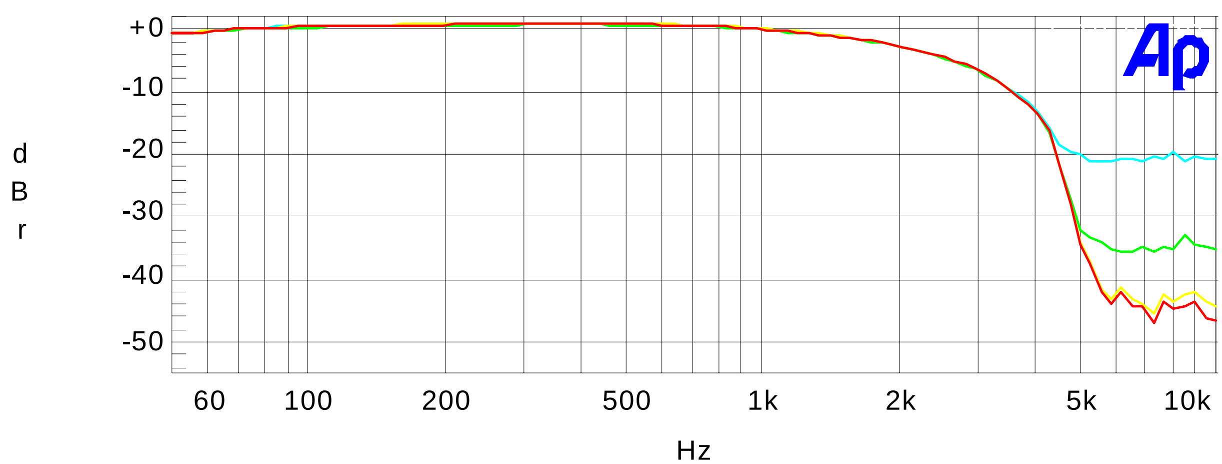
4.5.3 Chevrolet 2000 Suburban

Category	OEM auto
AGC Threshold (dBm)	-115
RF Overload (dBm)	>0
RF Test level (dBm)	-85
SNR, unweighted (dB)	41
THD, 400 Hz (%)	1.3
THD, 50 Hz (%)	1.4
SNR, CCIR (dB)	-27
-3 dB Frequency (Hz)	2100
-10 dB Frequency (Hz)	3500

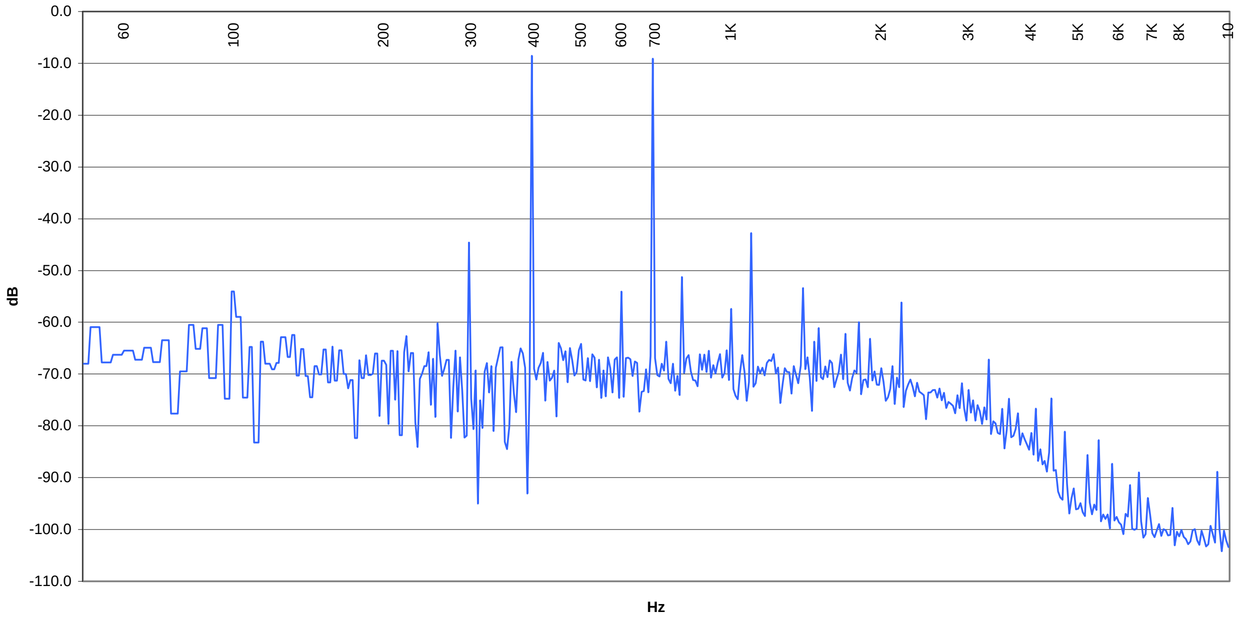
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**				**D/U (dB)**			
	+3 0	+15	+6	0	+30	+15	+6	0
10	-	-	22	18	-	34	24	18
-10	-	-	23	18	-	34	25	18
7	-	-	25	23	-	42	33	26
-7	-	-	25	23	-	42	32	25
6	-	-	26	26	-	48	43	35
-6	-	-	27	26	-	51	41	34
5	-	-	-	26	-	57	54	44
-5	-	-	-	25	-	54	48	45

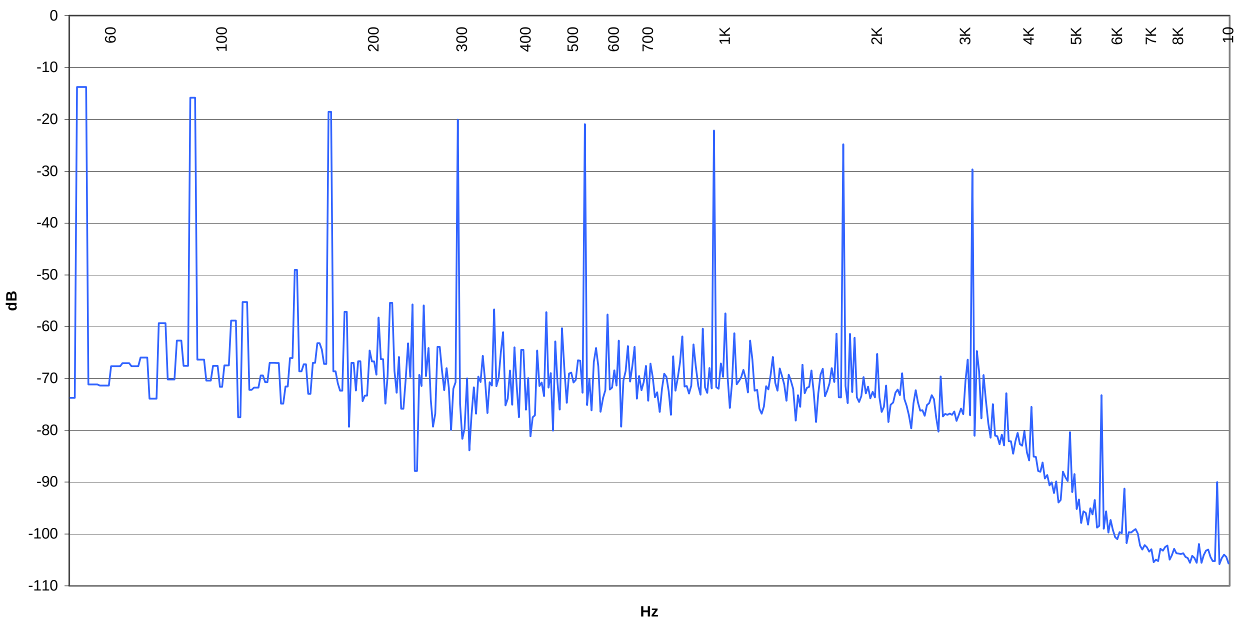
AM Frequency Response at -85, -70, -55 & -40 dBm (cyan, green, yellow, red)



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



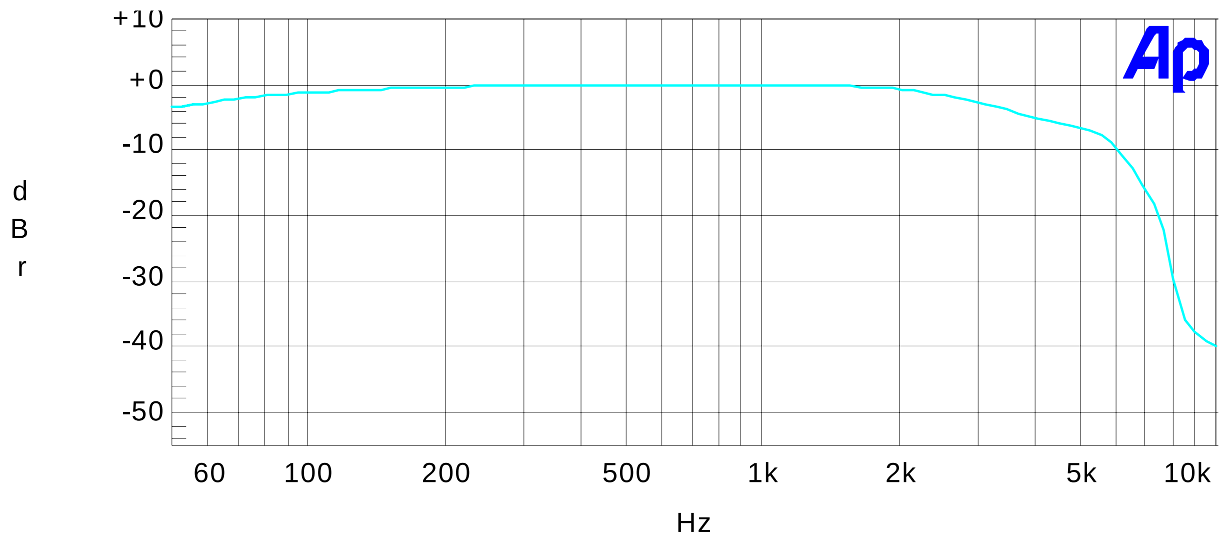
4.5.4 Ford 2002 Mustang

Category	OEM auto
AGC Threshold (dBm)	-100
RF Overload (dBm)	-5
RF Test level (dBm)	-70
SNR, unweighted (dB)	54
THD, 400 Hz (%)	0.7
THD, 50 Hz (%)	0.7
SNR, CCIR (dB)	-44
-3 dB Frequency (Hz)	3200
-10 dB Frequency (Hz)	6100

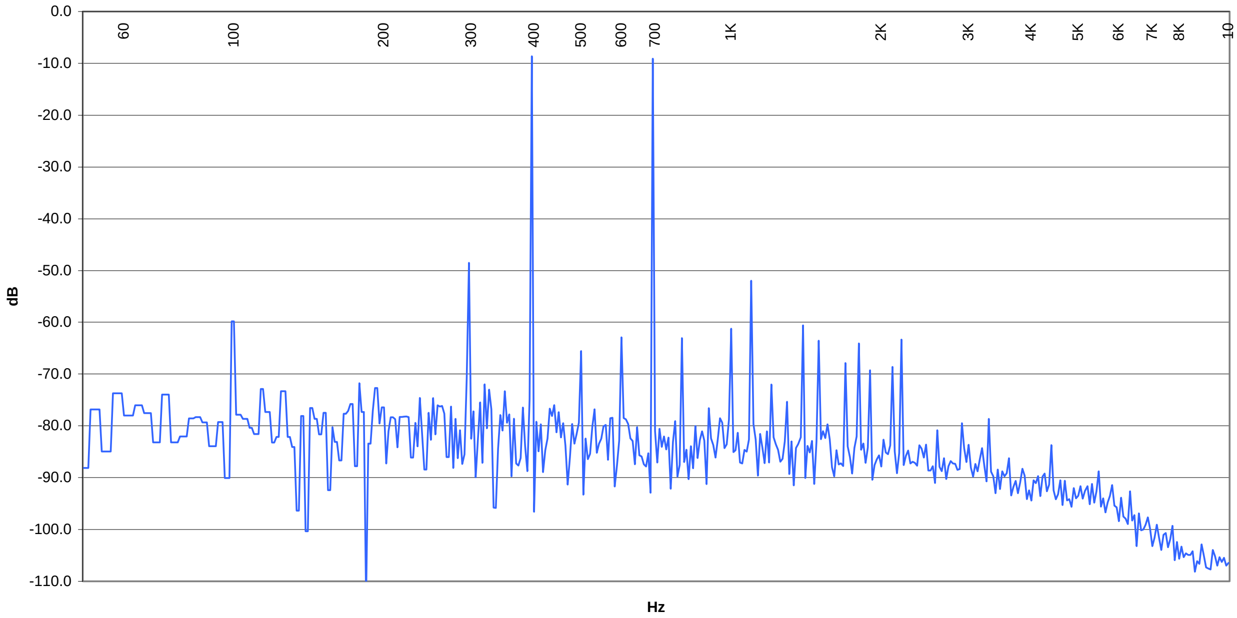
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	42	29	28	14
-10	40	31	26	12
7	44	33	30	20
-7	42	30	23	15
6	44	34	25	23
-6	43	31	23	16
5	44	36	29	22
-5	43	34	23	19

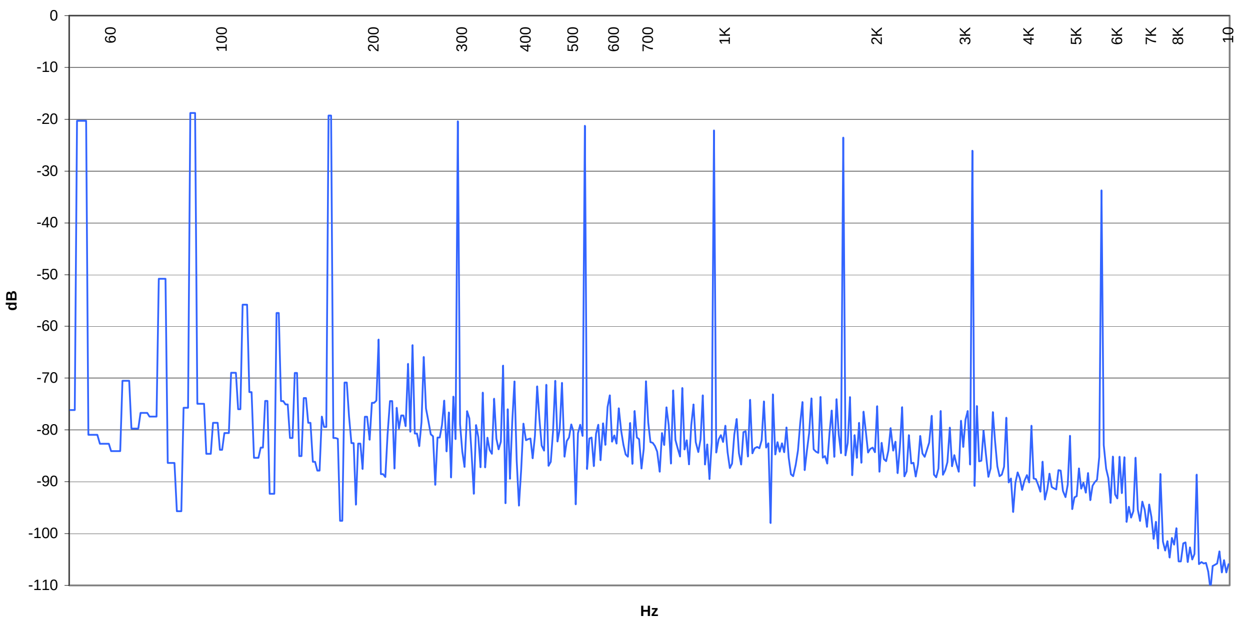
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



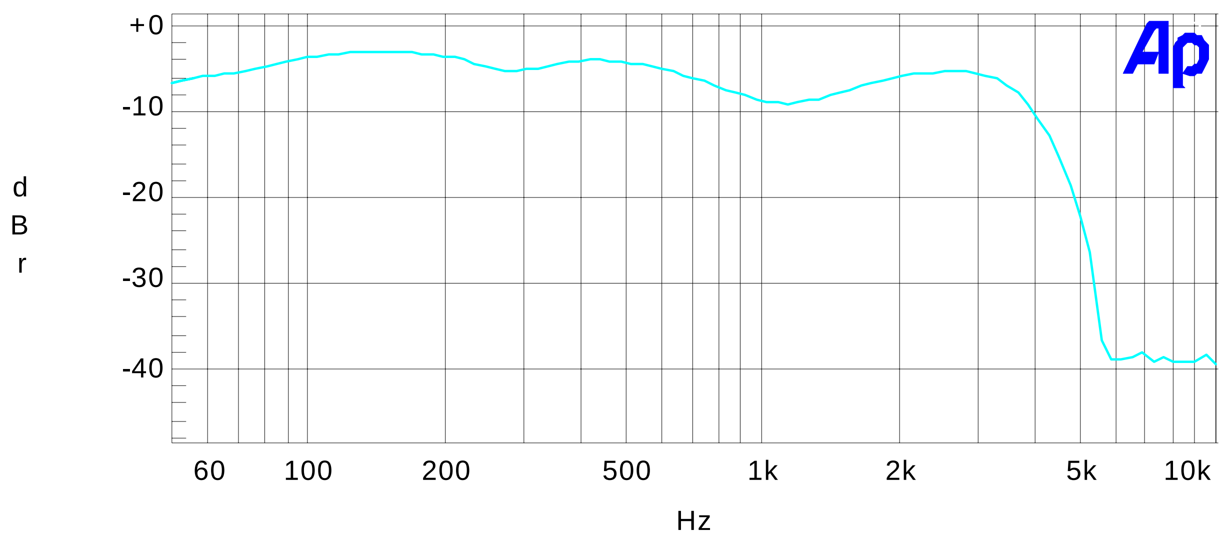
4.5.5 Honda 2002 Accord

Category	OEM auto
AGC Threshold (dBm)	-105
RF Overload (dBm)	>0
RF Test level (dBm)	-75
SNR, unweighted (dB)	37
THD, 400 Hz (%)	1.8
THD, 50 Hz (%)	1.9
SNR, CCIR (dB)	-39
-3 dB Frequency (Hz)	4200
-10 dB Frequency (Hz)	4800

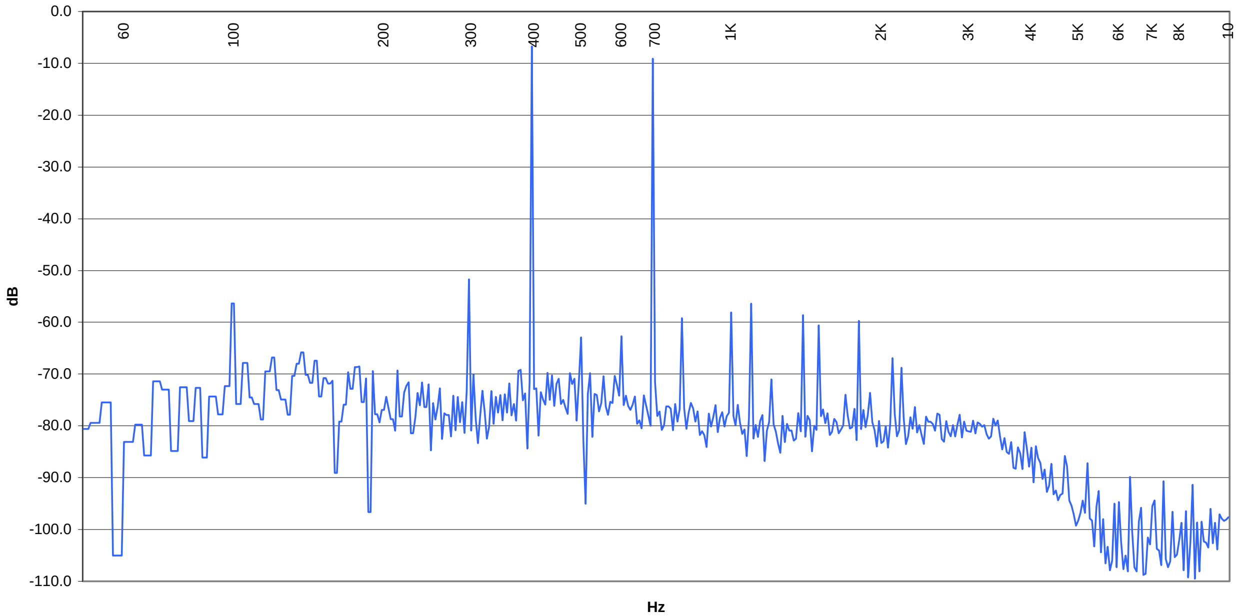
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	37	27	17	12
-10	36	25	16	10
7	-	32	23	19
-7	-	32	22	15
6	-	37	30	26
-6	-	35	27	29
5	-	39	37	33
-5	-	38	37	31

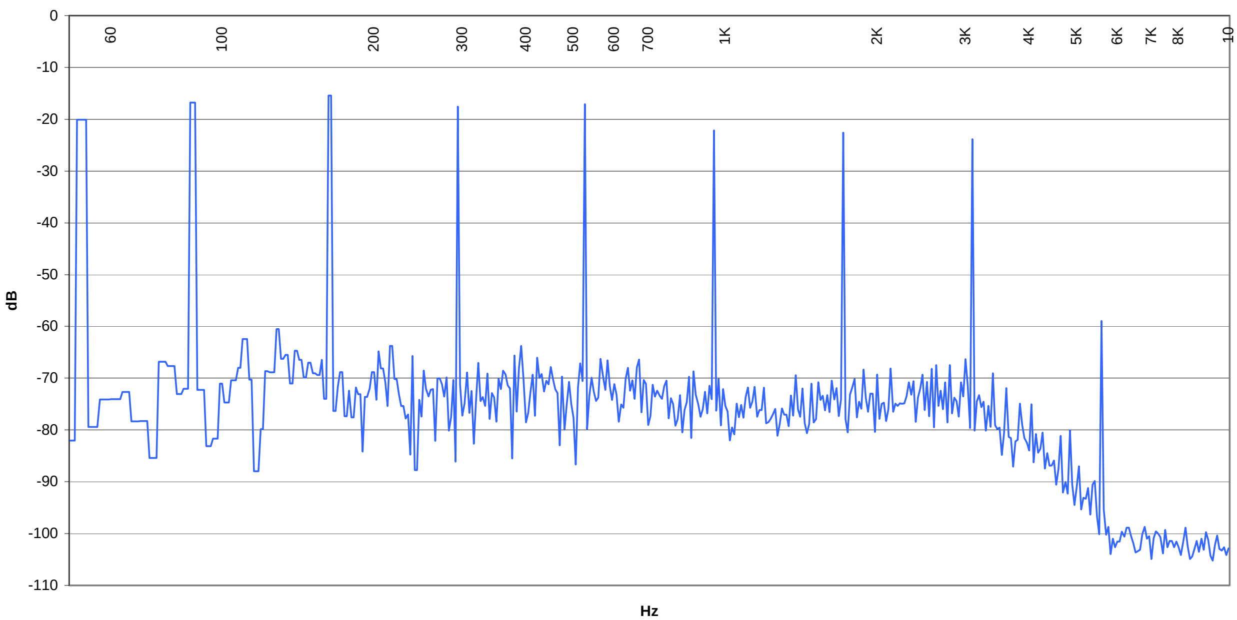
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



4.6 Clock Radios

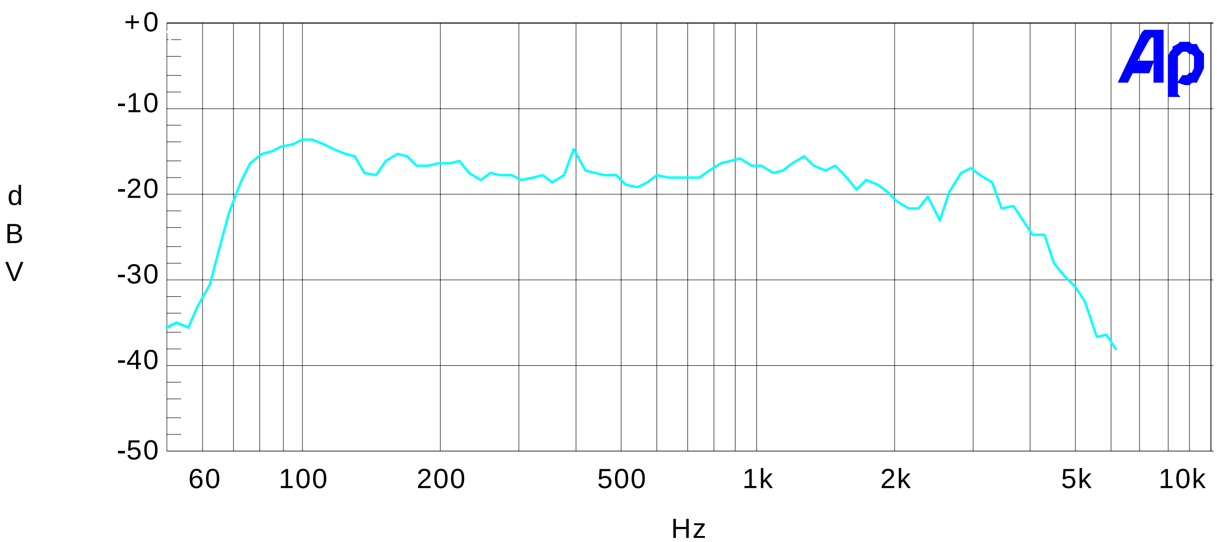
4.6.1 Boston Acoustics Receptor-P

Category	Clock
AGC Threshold (dBm)	-80
RF Overload (dBm)	-10
RF Test level (dBm)	-45
SNR, unweighted (dB)	37
THD, 400 Hz (%)	4.1
THD, 50 Hz (%)	1.6
SNR, CCIR (dB)	-33
-3 dB Frequency (Hz)	3400
-10 dB Frequency (Hz)	4500

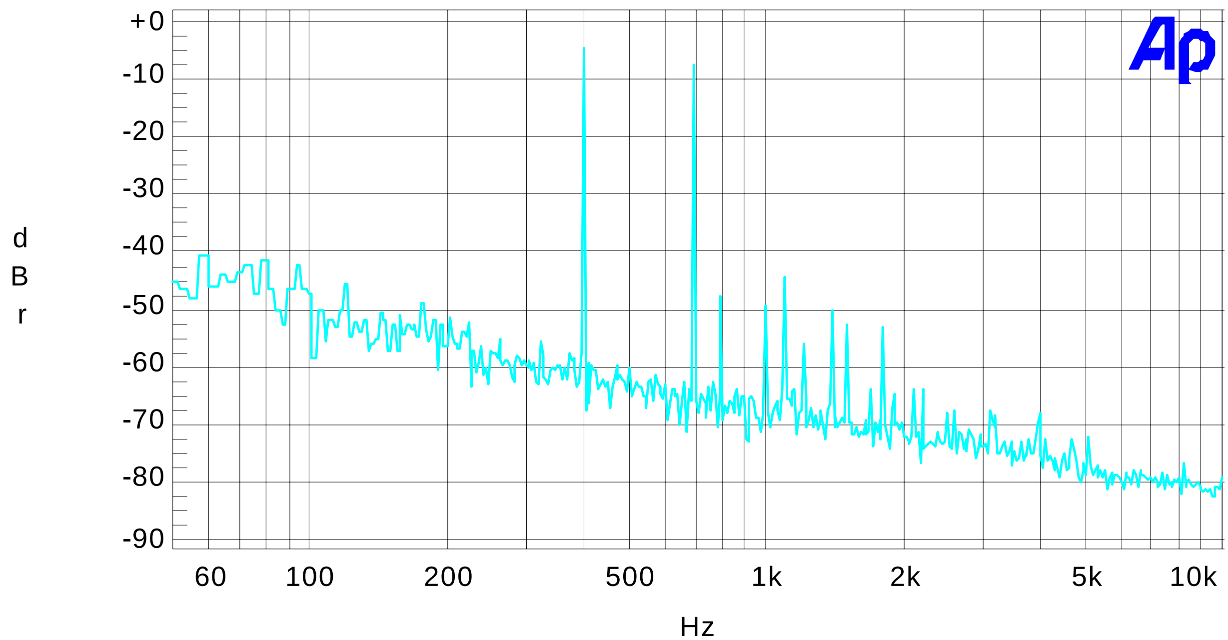
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	D/U (dB)			
	+30	+15	+6	0
10	33	26	18	12
-10	33	29	21	15
7	33	29	21	21
-7	33	32	25	25
6	33	31	24	19
-6	33	33	28	23
5	33	32	27	27
-5	33	33	30	30

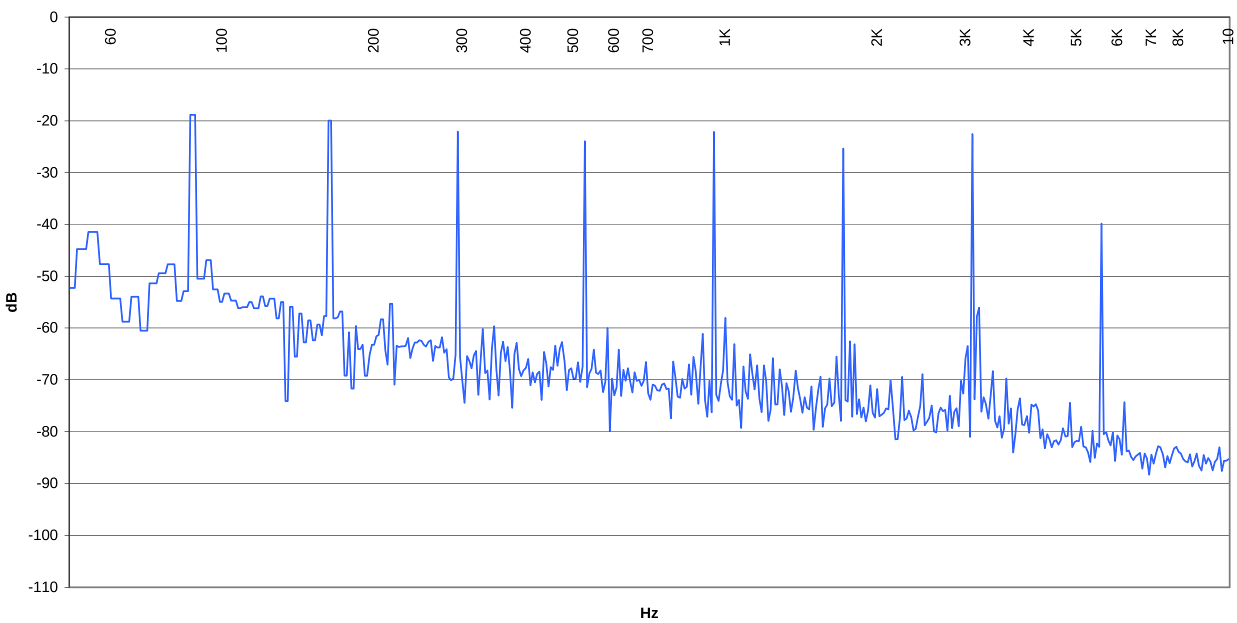
Acoustic Measurement of AM Frequency Response (see text)



Acoustic Measurement of 2-Tone IM Distortion (see text)



Acoustic Measurement of 10-Tone IM Distortion (see text)



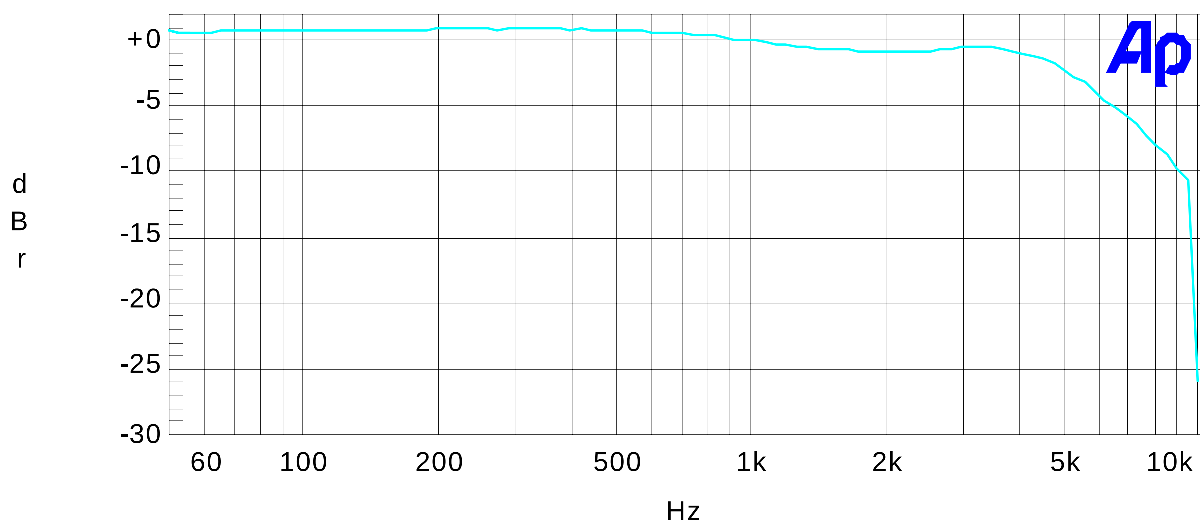
4.6.2 Curtis CR-4966

Category	Clock
AGC Threshold (dBm)	-60
RF Overload (dBm)	-30
RF Test level (dBm)	-45
SNR, unweighted (dB)	38
THD, 400 Hz (%)	1.4
THD, 50 Hz (%)	1.7
SNR, CCIR (dB)	-27
-3 dB Frequency (Hz)	5400
-10 dB Frequency (Hz)	9400

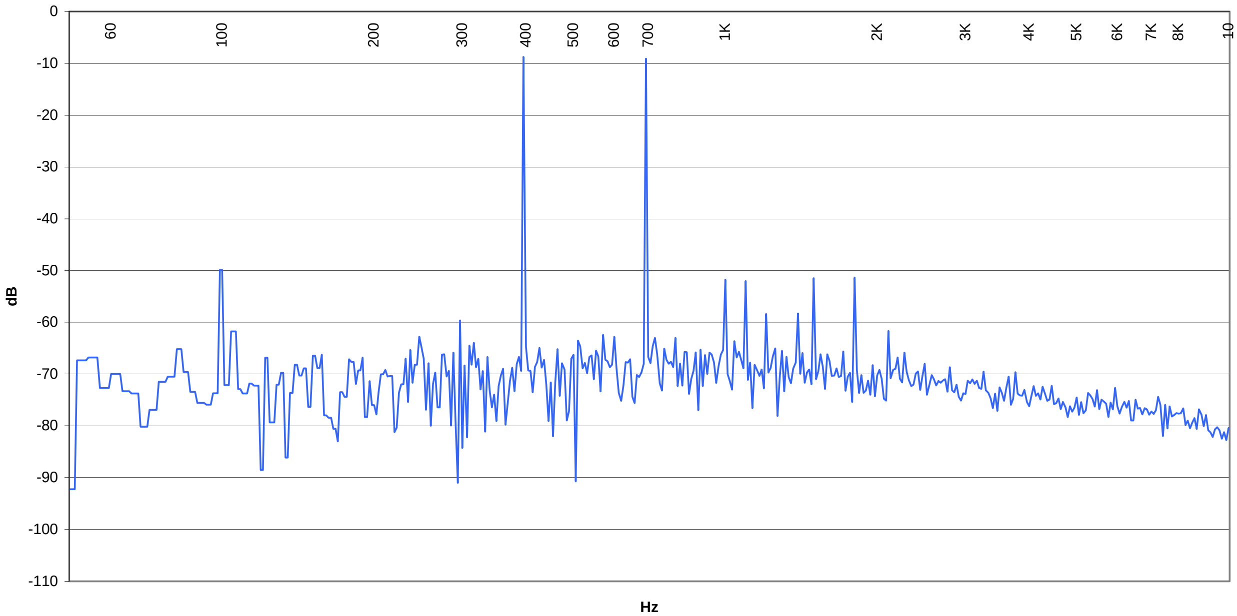
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	26	25	20	14
-10	23	15	6	1
7	27	25	21	16
-7	22	15	6	1
6	26	25	22	17
-6	22	15	7	2
5	25	26	22	18
-5	22	15	7	2

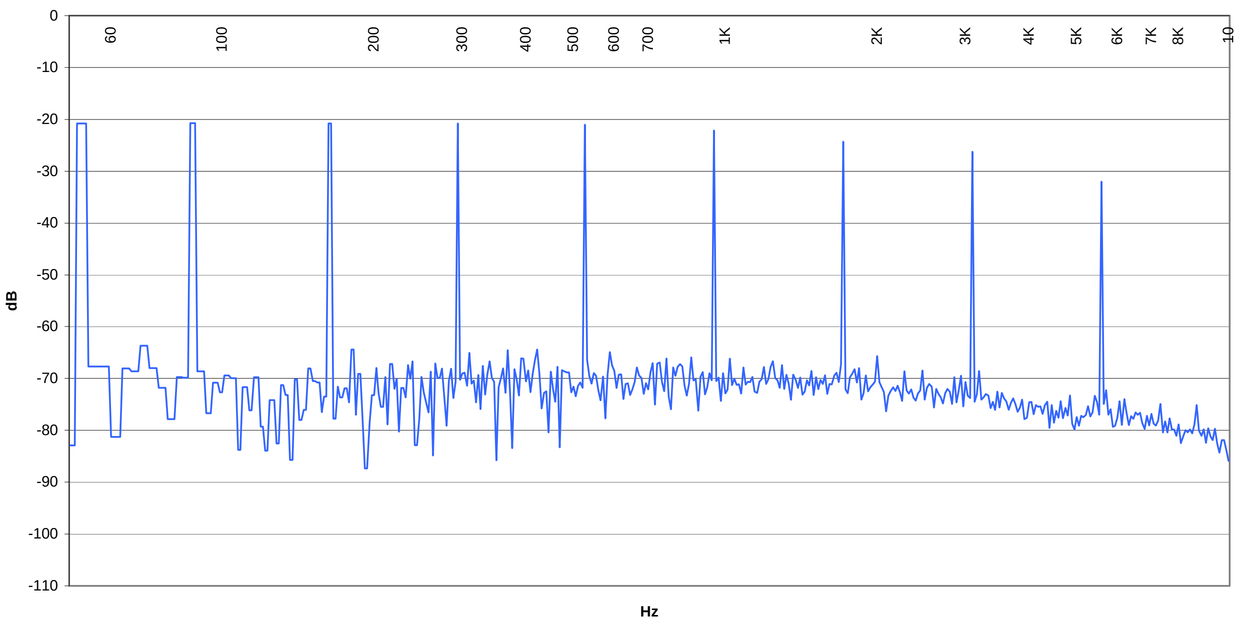
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



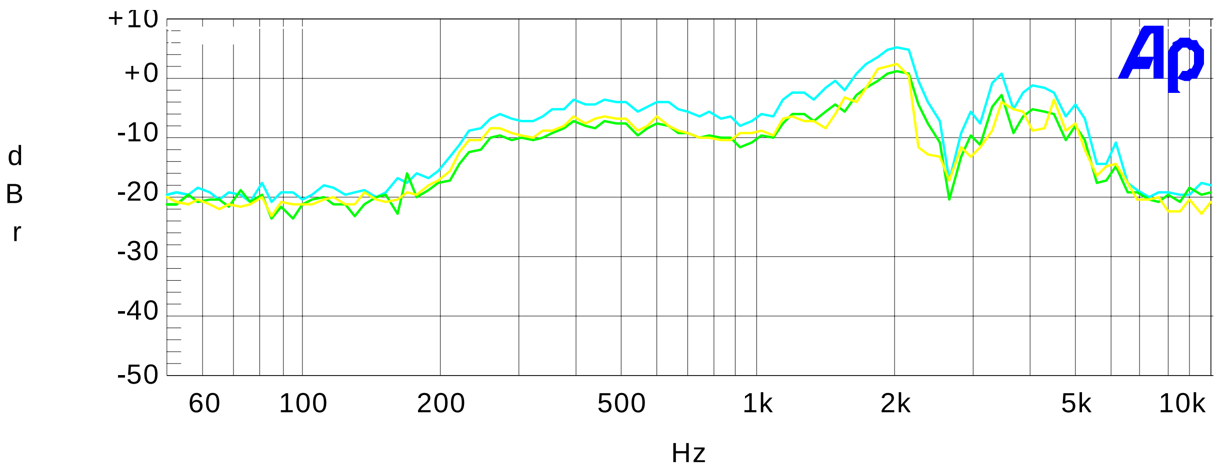
4.6.3 Sima First-Alert WX-39

Category	Clock
AGC Threshold (dBm)	-50
RF Overload (dBm)	-30
RF Test level (dBm)	-40
SNR, unweighted (dB)	31
THD, 400 Hz (%)	3.3
THD, 50 Hz (%)	none
SNR, CCIR (dB)	-21
-3 dB Frequency (Hz)	2200
-10 dB Frequency (Hz)	5300

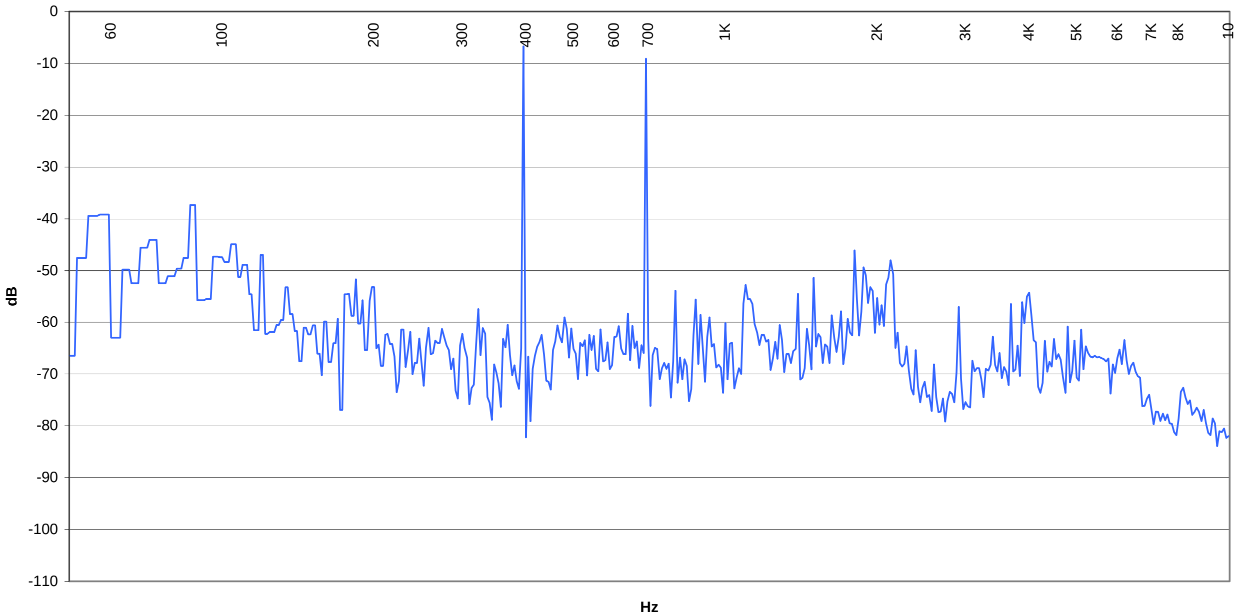
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	21	21	19	15
-10	21	21	18	13
7	21	21	20	19
-7	21	21	19	18
6	21	21	19	19
-6	21	21	19	18
5	21	21	21	20
-5	21	21	21	18

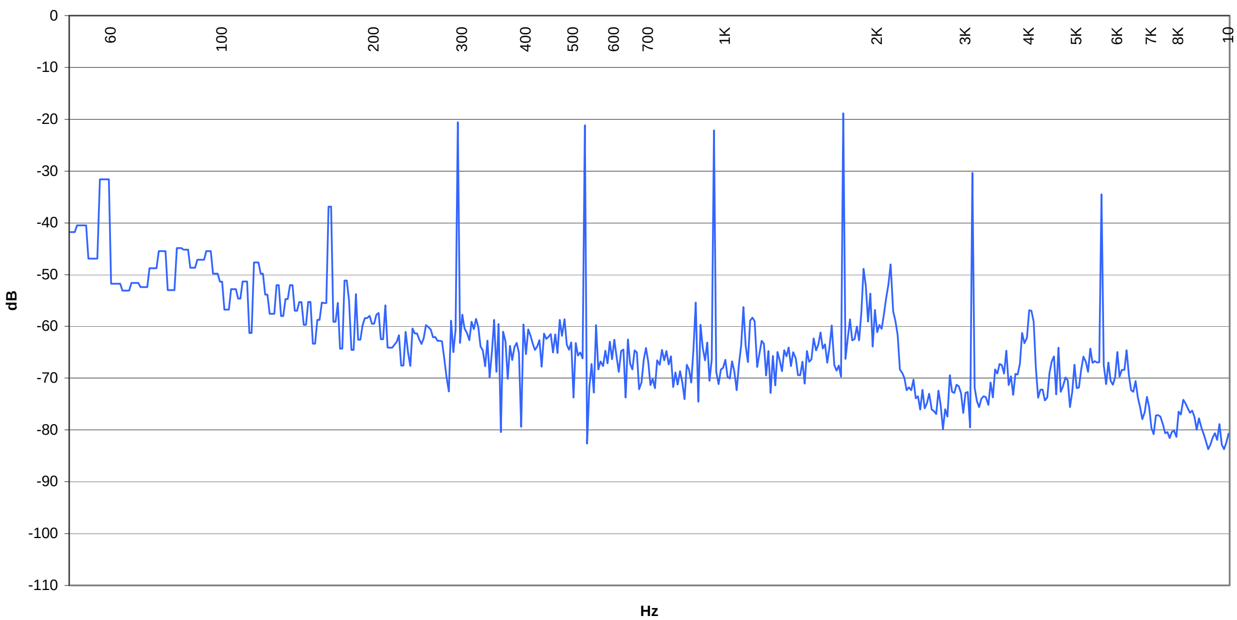
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



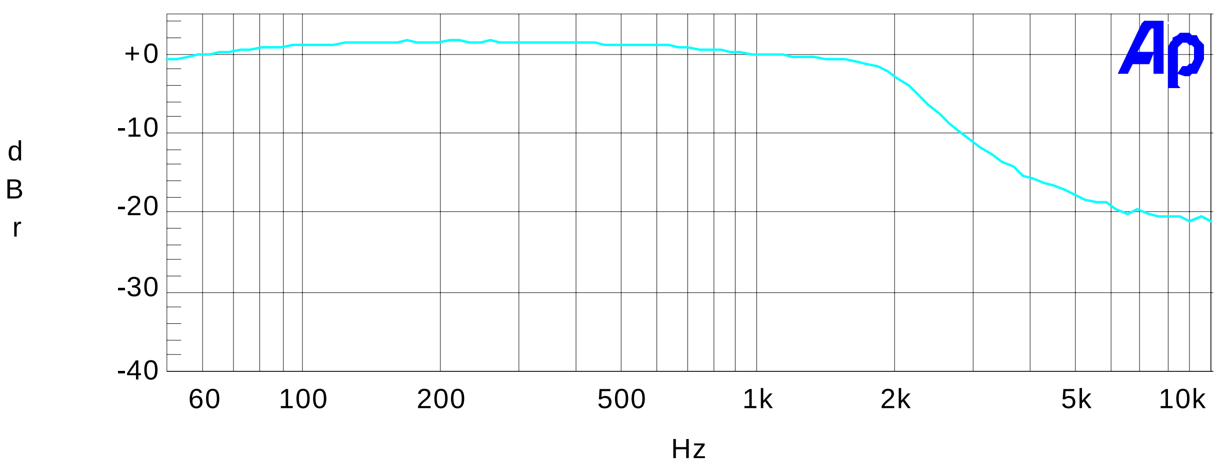
4.6.4 Audiovox CE256

Category	Clock
AGC Threshold (dBm)	-67
RF Overload (dBm)	>0
RF Test level (dBm)	-39
SNR, unweighted (dB)	41
THD, 400 Hz (%)	2.3
THD, 50 Hz (%)	3.4
SNR, CCIR (dB)	-21
-3 dB Frequency (Hz)	2000
-10 dB Frequency (Hz)	2900

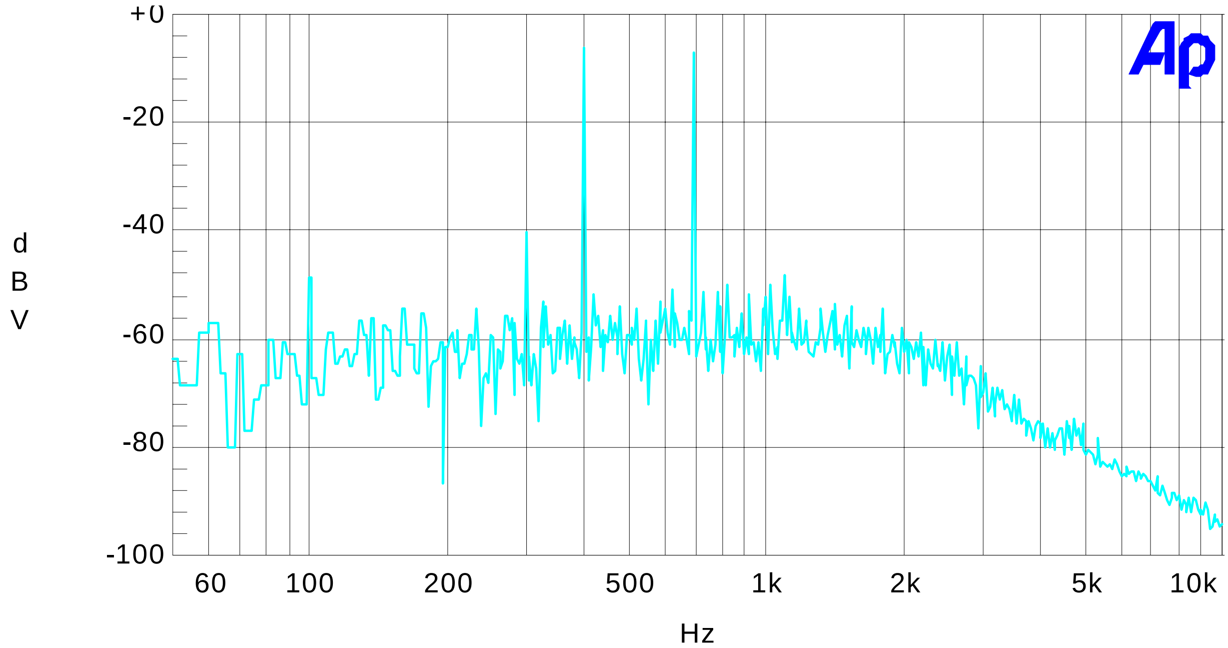
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	D/U (dB)			
	+30	+15	+6	0
10	21	20	21	17
-10	21	18	21	15
7	21	21	21	20
-7	21	20	21	19
6	21	21	21	20
-6	21	21	21	19
5	21	21	21	21
-5	21	21	21	20

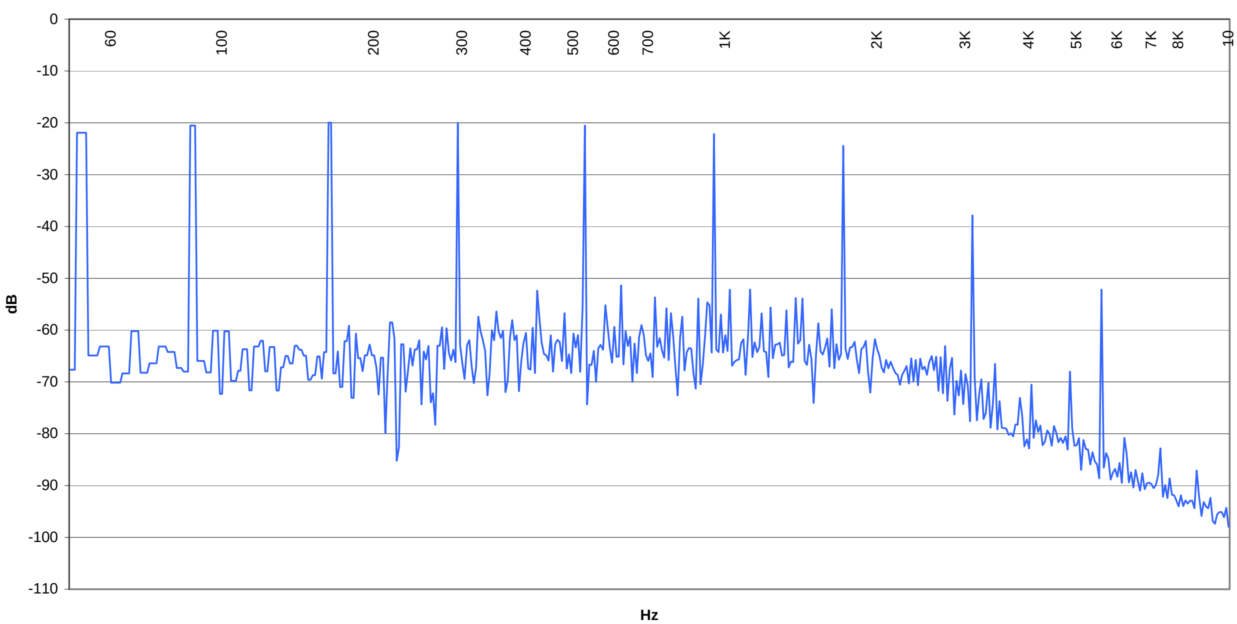
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



4.7 HD Radios

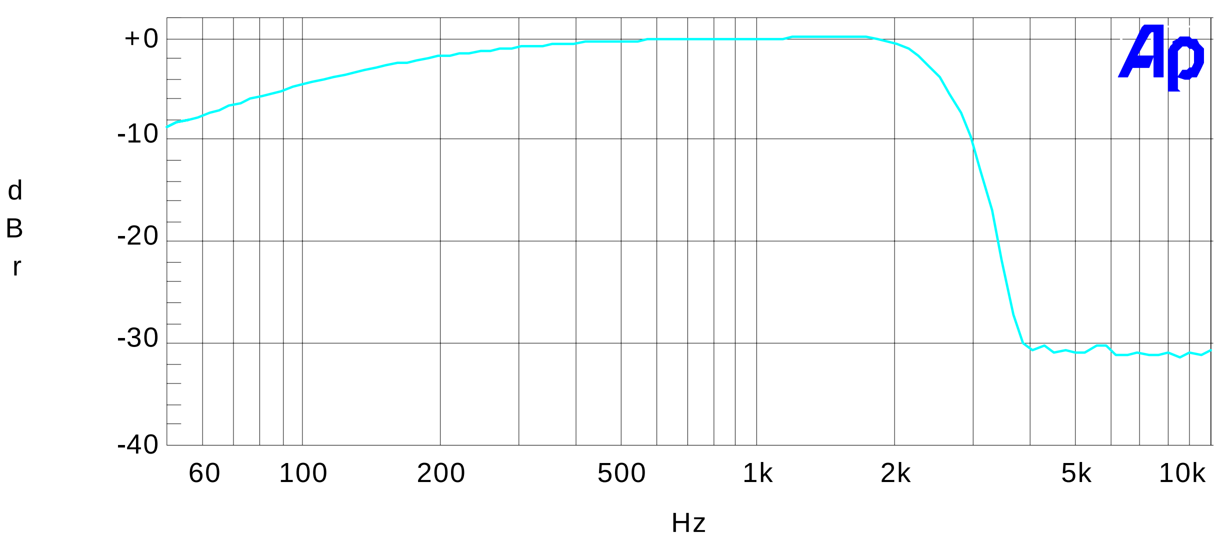
4.7.1 JVC KD-SHX900

Category	HD Car Radio
AGC Threshold (dBm)	-75
RF Overload (dBm)	-5
RF Test level (dBm)	-40
SNR, unweighted (dB)	40
THD, 400 Hz (%)	0.8
THD, 50 Hz (%)	0.7
SNR, CCIR (dB)	-30
-3 dB Frequency (Hz)	2400
-10 dB Frequency (Hz)	3000

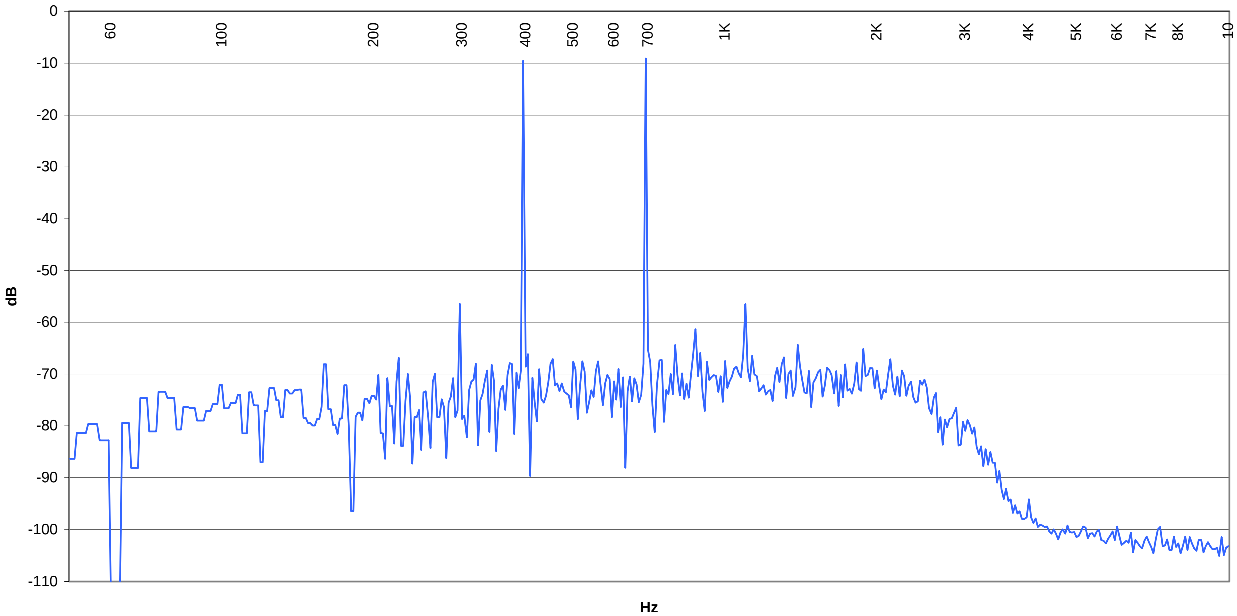
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	-	29	22	22
-10	-	29	23	22
7	-	30	29	29
-7	-	30	30	29
6	-	30	30	30
-6	-	30	30	30
5	-	30	30	30
-5	-	30	30	30

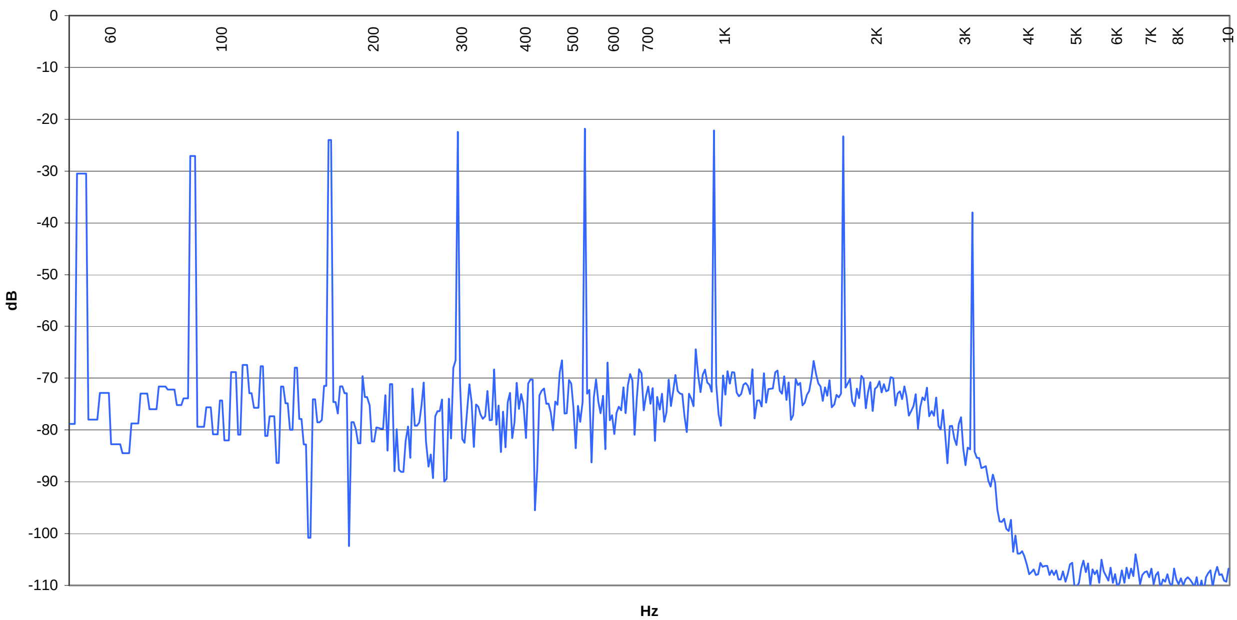
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



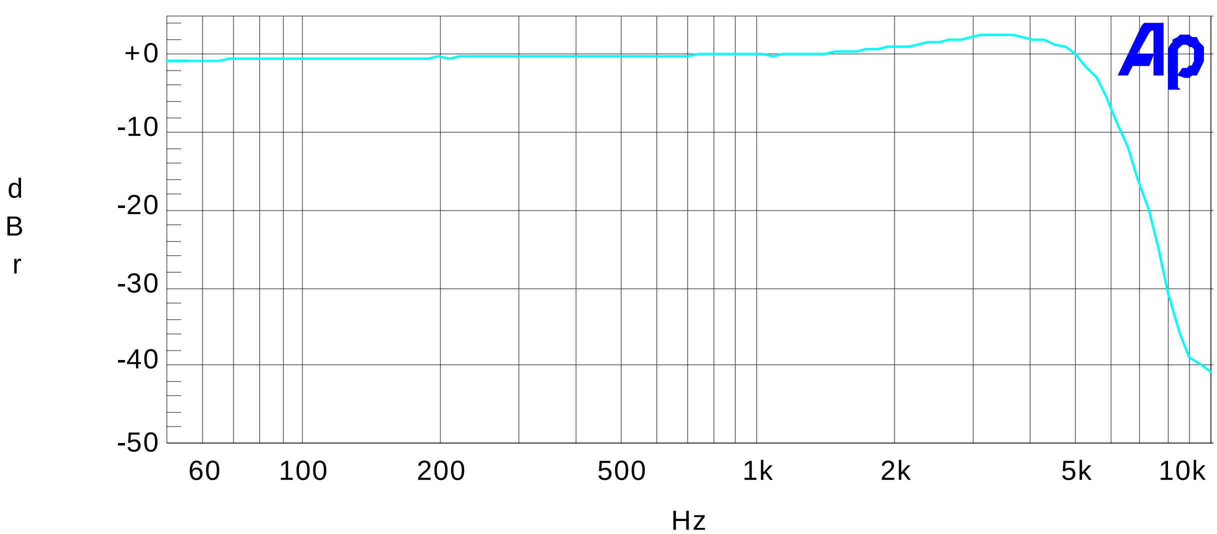
4.7.2 Panasonic CQ-CB9900U

Category	HD Car Radio
AGC Threshold (dBm)	-105
RF Overload (dBm)	-5
RF Test level (dBm)	-50
SNR, unweighted (dB)	52
THD, 400 Hz (%)	0.6
THD, 50 Hz (%)	0.6
SNR, CCIR (dB)	-51
-3 dB Frequency (Hz)	5600
-10 dB Frequency (Hz)	6400

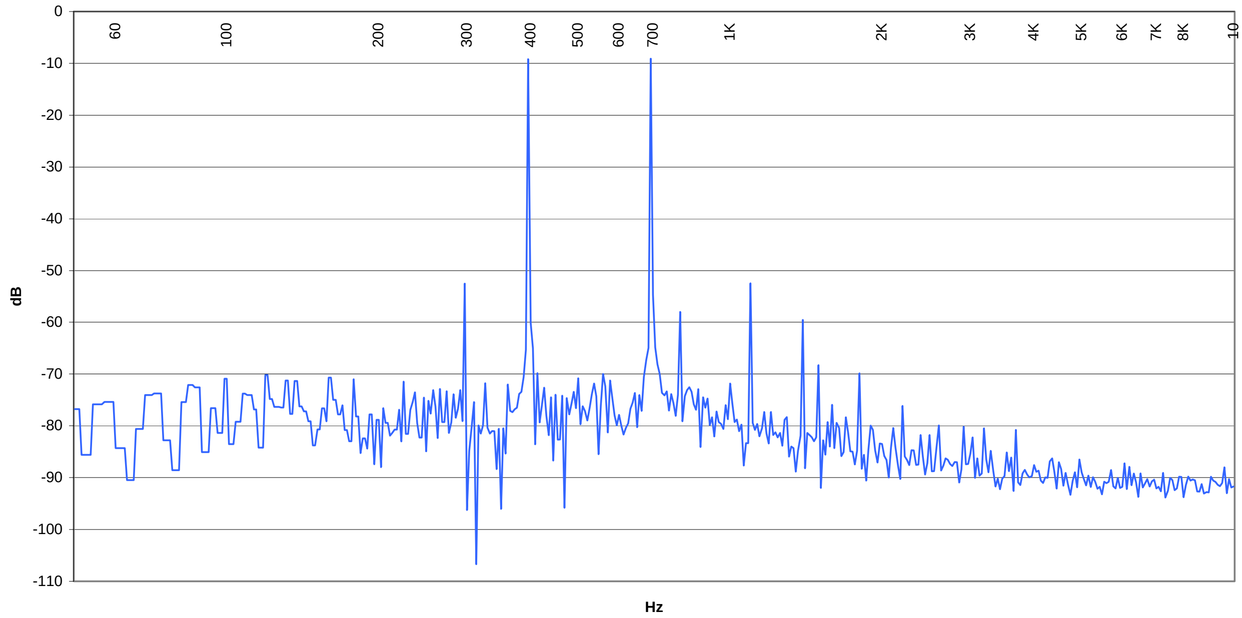
Psophometer-Based Adjacent-Channel Interference

LPF (kHz)	**D/U (dB)**			
	+30	+15	+6	0
10	42	28	22	15
-10	40	26	27	13
7	45	42	38	24
-7	44	41	37	20
6	48	49	48	25
-6	46	48	47	19
5	50	51	50	26
-5	49	50	49	20

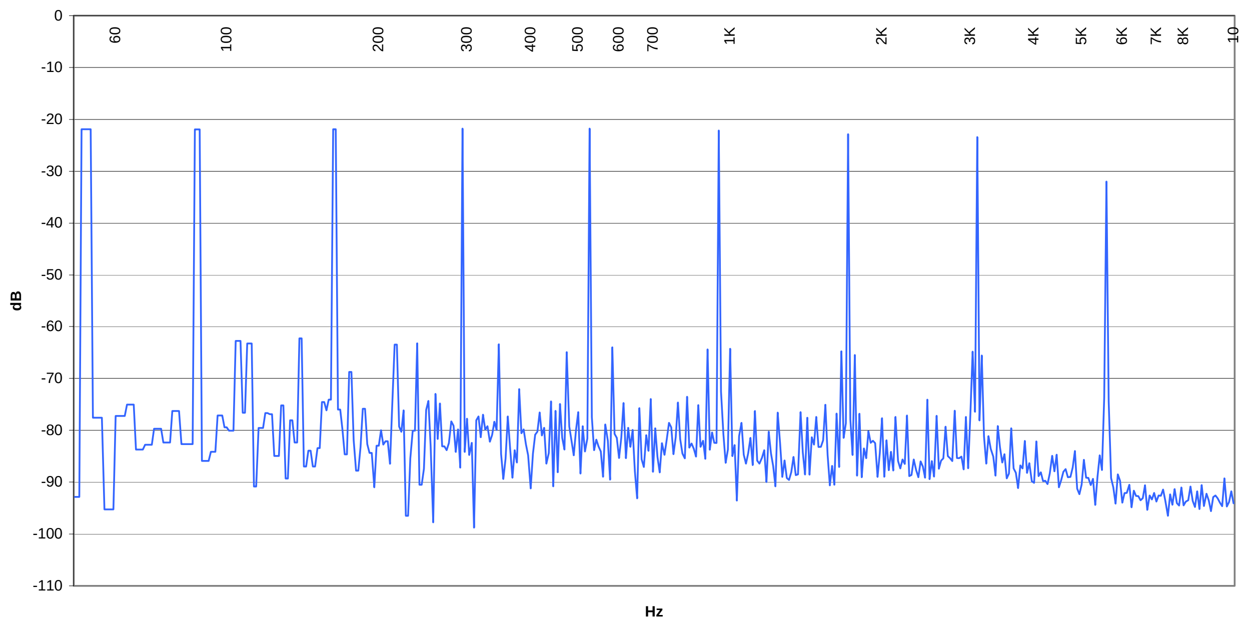
Measurement of AM Frequency Response



Measurement of 2-Tone IM Distortion



Measurement of 10-Tone IM Distortion



AM STUDY TASK GROUP TEST PROCEDURES – AM BAND
OVERALL COMMENTS

1. The test laboratory will provide a detailed certification of the test bed.
2. Appendix A is a list of the test results (resulting from these procedures) which must be included in the laboratory test record to be provided to the AMB of the NRSC at the conclusion of testing. Note that this list is not meant to suggest the format in which those results are to be presented in that record, but is simply an enumeration of those results.
3. Unless otherwise specified, the audio selections to be used as source material for desired and interfering channels are specified in the AM Study Task Group (AMSTG) audio test list.
4. The RF signal levels are set based upon definition in the AM laboratory tests.
5. Digital recordings of analog or digital audio indicated by these procedures are for archival and/or subjective evaluation purposes. All such recordings will be made in the following format: uncompressed linear 16-bit digital audio sampled at 44.1 kHz, and will be suitable for transfer to CD to facilitate further analysis.
6. The detailed procedure for RF noise measurements will be supplied.
7. Unless otherwise specified, 2 transmitters will be used to generate undesired signals in co- and adjacent-channel interference tests.
8. Unless otherwise specified, audio noise and interference measurements will be made using the weighted quasi-peak (“WQP,” CCIR weighting filter) measurement technique.
9. Unless otherwise specified, modulation interferers, and modulation of signals used for analog reference recordings, will conform to the NRSC standard AM mask (i.e. 10 kHz nominal audio bandwidth).
10. Analog modulation level shall be established using a 400 Hz tone and with the audio processor in bypass mode

AM STUDY TASK GROUP LABORATORY TEST PROCEDURES – AM RESPONSE CALIBRATION					
Test Group	Test & Impairment	TEST DESCRIPTION Note: 1. Pulsed USASI noise will be used as the modulation source material for all calibration tests.	Desired Signal Level	Type of Evaluation	Test Results Data to be Recorded
Calibration	1 Power	1. Average power will be measured.	NA	Objective	Average power level
	2 Spectrum (each test day or as needed)	1. A spectrum analyzer plot of the system RF spectrum will be taken for each test day (or as needed). 2. Spectral occupancy will be measured using a spectrum analyzer with a peak hold of 10 minutes, video bandwidth greater than 10 kHz, RBW 300 Hz, and sweep span of 100 kHz (derived from 47 CFR §73.44).	M	Objective	Spectrum plot
	3 Proof-of-performance	1. A proof-of-performance test will be conducted. A high quality demodulator will be used for this test.	Varying	Objective	Frequency response, audio SNR, and audio THD
	4 Monitor calibration (as needed)	1. Modulation monitors will be calibrated with 100% modulation by observing the resulting trapezoid pattern in the modulated envelope waveform, using an oscilloscope.	NA	Objective	Calibration results
	5 Test bed calibration (prior to test)	1. All of the critical components in the test bed, including the transmission path simulator, attenuators, combiners, filters, generators, and measuring instruments, will be certified by the testing laboratory prior to tests.	NA	Objective	Calibration results

Test Group	Test & Impairment	TEST PROCEDURE	Type of Evaluation	Test Results Data to be Recorded
		Notes: This section of the test program is focused on the electrical audio response of each radio in the test population. Frequency response will be measured at the loudspeaker output or headphone output (if loudspeaker outputs are not available). The receiver under test will be connected to an accepted AM RF Generator that is capable of modulating an NRSC pre-emphasized audio response out to 10 kHz. The modulated test signal should exhibit good characteristics in phase stability, THD and Multitone/IMD. The subsequent received voltage, phase, noise and Multitone/IMD responses will be plotted for each radio tested for its category. Upon completion of receiver testing, an audio bandwidth distribution histogram will be plotted for the receiver population. The distribution of frequency responses will be examined to determine whether any unusual deviation in audio performance exists. A wide difference among the categories may indicate further review by the NRSC AM Study Task Group for changes in receive test populations or test protocol. **Response Test Procedure** SNR measurements are made using unweighted RMS and CCIR-468 weighted quasi-peak detection. Automobile and portable receivers are connected to 4-ohm loads. Home receivers are connected to 8-ohm loads. Tone controls are set to center positions. Balance and fade controls are set to center positions. Loudness control, if available, is set to off position. All measurements are taken using the left channel unless otherwise noted. The 30 kHz Low Pass Filter on the Audio Analyzer is turned on. The receiver tuning frequency is 1000 kHz. The general configuration of the test bed for receiver audio measurements is illustrated in Figure-1, at the end of the procedural document. All required audio measurements may be performed with the audio analyzer specified herein, including the generation of necessary audio test signals. However, since the analyzer does not include standard lowpass filtering or preemphasis an audio processor is placed ahead of the AM modulation input to the RF Generator. An Audio Tone Generator is shown optionally for miscellaneous modulation lineup purposes.		

	1 RF Connection to radio under test	RF Connection to Receiver Under Test (NRSC-3, 3.4.1): A test loop antenna, driven by the RF output of a test signal generator, shall be placed within 24 inches (60 cm) from the loop/loopstick antenna of the receiver under test, in the plane of strongest signal performance. If the receiver under test does not normally utilize a loop or loop stick antenna, the 50 ohm RF output of a test signal generator may be directly connected to the AM antenna input of the receiver under test using a matching network, if another input impedance is known. Determination of the Optimum RF Input Level for audio testing is a two step process: 1) First, the receiver under test is connected to the test bed and measurements are taken with IM distortion signal modulation (such as 400 Hz and 700 Hz mixed 1:1 at 70% modulation) at the maximum setting of the RF attenuator feeding the receiver.* With the receiver volume control at midrange the audio output is monitored and the RF input power is increased (RF generator output minus attenuator value). The RF level at which audio level abruptly stops rising is noted. This is the point at which automatic gain control has begun limiting RF input. 2) Next, the amount of IM distortion is noted. The RF input power is again increased in steps while the IM distortion is monitored. The RF level at which the 1.1 kHz IM distortion product rises abruptly or at drop in fundamental amplitude of 2 dB occurs is noted. This is the point of RF or mixer stage overload in the receiver that results in compression of the modulation envelope. The Optimum RF Input Level for measurement is the arithmetic mean of the first and second RF level readings. *NOTE: Unless otherwise stated herein, the AP System One Channel A output is connected to the Orban Optimod 9200D, and the 9200D output connected to the MOD INPUT port of the HP 8647A in the EXT AC mode. Using a combination of the *Optimod 9200 PC Remote* software and front panel Channel 1 gain control, the 9200D controls are adjusted to pass the 1 kHz tone with no AGC or multiband gain control indications. The HP 8647A generator provides calibrated amplitude modulation (within ±5% or 0.44 dB up to 10 kHz) when the MOD INPUT is driven with a Optimal Input Voltage of 1.00 V P-P. The Optimal Input Voltage is achieved when "HI" or "LO" on the EXT AC display are not displayed. Required modulation level, such as 70% is entered on the DATA keypad and is occasionally confirmed with the Belar Wizard modulation monitor.	Objective	RF Level noted

2 Signal-to- Noise Ratio	The Analog Generator of the AP System One (AP) is used to generate a 1 kHz tone at 70%modulation. The built-in Analog SNR test is used to perform the measurements, according to the following procedure: 1. As noted in the previous section, the AP output is connected to the Optimod 9200D, which is connected to the HP 8647A SNR is selected from the AP System One toolbar, loading the procedure, including on-screen instructions. Using a 1 kHz tone from AM, the Channel 1 gain control on the 9200D is adjusted to provide the Optimum Input Level on the HP 8647A generator. 2. The audio output of the receiver under test is connected to the AUX INPUT of the AP System One. On the APWIN Regulation panel, the “Enable during each step of the sweep” option is disabled. The Analog Analyzer is set to monitor AUX on Channel A. 3. “Continue Procedure” is selected on the APWIN Instructions panel, reference level and THD are presented. If values are within acceptable range, procedure is continued. If reference level is unacceptable, the AP System One begins the procedure again. 4. The AP low pass filter (LPF) is set to 30 kHz. The AP detector is set to RMS. All other noise measurement settings are left at AP defaults, and the procedure is continued. 5. The AP System One returns the noise relative to the reference level, along with THD and measurement bandwidth, which are recorded with the receiver data. The HP 8903B Audio Analyzer provides the quasi-peak response and CCIR/ARM weighting necessary for psophometer measurement of noise, relative to 1 kHz at 70% modulation. 1. The AP System One output is connected to the MOD INPUT of the HP 8647A. The AP System One Frequency is set to 1 kHz sinewave. The AM FUNCTION is set to 70% modulation. 2. The audio output of the receiver under test is connected to the HIGH input of the 8903B. The quasi-peak response (invoked by entering a 5.7 SPC command) and CCIR/ARM weighting filter are enabled. The 30 kHz LP FILTER is also engaged. 3. The 8903B is set to the dB RATIO mode for 0.00 dB. The tone modulation is removed from the AP System One. The CCIR quasi-peak noise level is measured from the right-hand display in dB. This SNR measurement is recorded as a positive dB value in the receiver data log.	Objective	SNR noted
3 Frequency Response & Relative Phase	The frequency response for each receiver is measured using an RF level, as previously described. Audio Reference Level shall be set to 70% modulation with a 400 Hz tone. All measurements are taken with the volume control at midrange as noted above. The frequency response is to be measured from 50 Hz to 10 kHz using the AP System One frequency sweep function with 100 steps. The relative phase response will be noted at each recorded test frequency.	Objective	Frequency Response Plotted, Relative Phase Noted
4 Total Harmonic Distortion (THD)	The THD of each receiver is measured using 50 Hz and 400 Hz tones independently, each at 70% modulation. The measurements are made using the same RF level as employed for the response measurements. An Intermodulation (IMD) measurement is made using the dual tones of 400 Hz and 700 Hz at 70% modulation. Measurements are taken using the Audio Precision System One.	Objective	THD Noted

	4 Multitone Distortion Components	The multitone test signal consists of a 10 sine waves at frequencies distributed across the audio spectrum at the same amplitude. The frequencies of the sine waves are to be logarithmically spaced across the spectrum from 30 Hz to 10 kHz. The signal frequencies are integer multiples of a basic frequency, which is the sample rate divided by the generator waveform length. For a 48 kHz sample rate and generator buffer length of 8192, the corresponding basic frequency is 5.859375 Hz. The exact frequencies should be checked to ensure that one is not a 2nd or 3rd harmonic of another frequency to leave those bins free for measurement of harmonic distortion products. The AP output level is adjusted for 70% peak modulation. **Multitone Analysis** The multitone signal, after passing through the receiver under test, is captured into the AP System One and an FFT is performed. Rather than sending a complete FFT analysis to the computer for display, additional post-processing is done following the FFT to extract the most relevant audio performance information: • Total distortion and noise is plotted from the amplitudes of all FFT bins except those that contain the multitone sinewave signals. • For comparison, noise will be measured in the absence of the multitone signal from the same FFT bins used above.	Objective

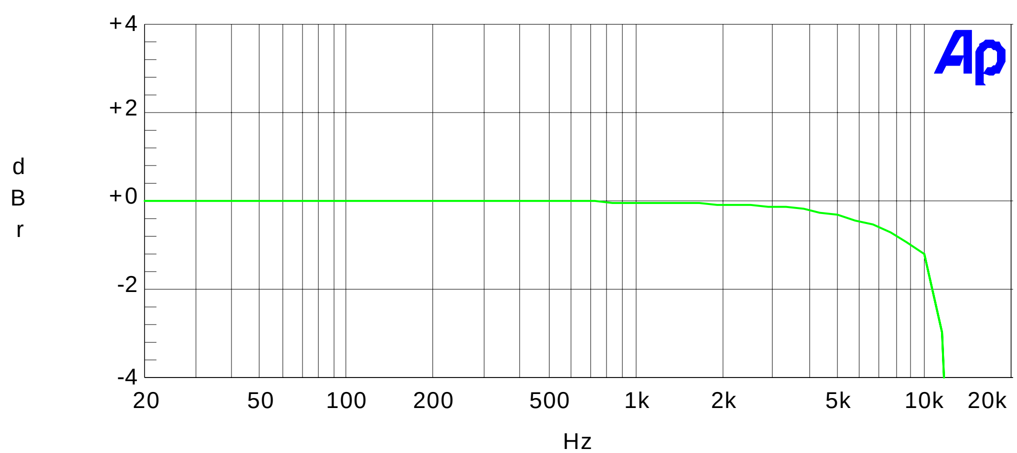
AM STUDY TASK GROUP LABORATORY TEST PROCEDURES – AM BAND ANALOG COMPATIBILITY (w/adjacent channel interferer)				
Test Group	Test & Impairment	DESCRIPTION Notes: 1. These tests will measure analog-to-analog interference. The desired signal XMTR will be modulated in accordance with the NRSC standard AM mask or specified reduced bandwidth, and the undesired signal XMTR will be modulated in accordance with the NRSC standard AM mask. 2. The test will be conducted with no background RF noise. 3. The undesired analog will be modulated with the interference selection. 4. For test receivers used for subjective evaluations, only the worst performing interference case (i.e., upper or lower) (as determined objectively) is used. 5. Figure-2 is a block diagram of the test setup.	Type of Evaluation	Test Results Data to be Recorded
Interference to an analog receiver with no other impairments	Single 1st adjacent	1. The desired signal will be modulated with 400 Hz tone, with 10kHz NRSC bandwidth. 2. The undesired signal will be modulated with xxx, with 10kHz NRSC bandwidth. 3. Using a lower 1st-adjacent channel interferer, with 10 kHz modulation bandwidth, the desired channel analog weighted quasi-peak (WQP) S/N ratio will be measured for D/U settings of +30 dB, +15 dB, +6 dB, and 0 dB. 4. Step 3 will be repeated using an upper 1st-adjacent channel interferer. 5. Steps 1 – 4 will be repeated for additional reduced audio bandwidths of the desired signal.	Objective	Analog WQP S/N ratio at specified D/Us with interferer (main channel audio)

Appendix M - Test Bed Calibration and Certification

AM STUDY TASK GROUP TEST PROCEDURES – AM BAND
TEST BED CALIBRATION

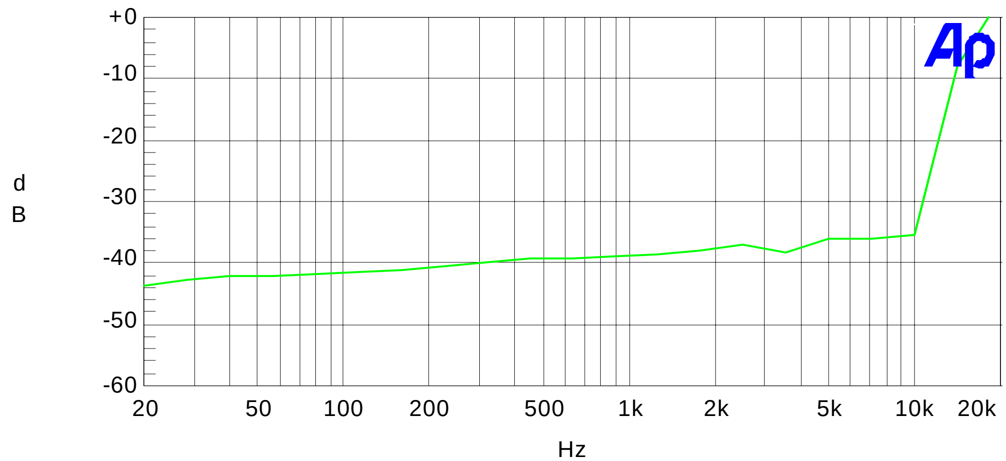
1. The AMSTG radio test bed was set up and operated at NPR Labs, National Public Radio, 635 Massachusetts Ave. NW, Washington, DC. Block diagrams of the set up with descriptions are included in AMSTG final report *Consumer Testing of AM Broadcast Transmission Bandwidth and Audio Performance Measurements of Broadcast AM Receiver*". John Kean of NPR Labs designed and supervised operation of the test bed.
2. All RF instrumentation was calibrated with NIST traceability by the equipment supplier, Naptech Test Equipment, Inc., 11270 Clayton Creek Rd., Lower Lake, CA 95457.
3. The frequency used for all receiver testing was 1000 kHz, which was determined to be unused at the test bed site. Nearest stations are WTEM, 980 kHz, Washington, DC and WWGB, 1030 kHz, Indian Head, MD.
4. Both desired channel and undesired channel RF generators were verified for linearity using an asymmetrically-clipped sine wave test signal from the *NAB Broadcast and Audio Test CD, Volume 1*.
5. Modulation calibration and distortion were verified by sideband analysis with a Belar Wizard modulation monitor. The frequency response of both RF generators (without the NRSC-1 compatible audio processors) was measured to be within ±0.2 dB from 20 Hz to 6 kHz, and thence down 1.3 dB at 10 kHz. Both generators performed substantially alike in this test.

Figure M-1 - Frequency response of RF generator at 70% modulation



6. Using a Belar Wizard modulation monitor, total harmonic distortion plus noise at 1 kHz with both generators was less than 1.1% THD at 70% modulation, as shown in Figure M-2. Both generators performed substantially alike in this test.

Figure M-2 - THD + Noise for RF generator at 70% modulation



7. In the course of testing, modulation and test bed frequency response was checked daily with the Belar Wizard modulation monitor.
8. RF output levels were checked periodically with a Hewlett-Packard 437B Power Meter with 8482A Power Sensor.
9. All RF cables were double-shielded coax and a shielded steel enclosure built by Ramsey Electronics was used for testing of radios without shielded metal cases. (Car radios, for example, always had shielded enclosures and antenna inputs.) Radios with supplied external loop antennas, such as the bookshelf systems, were tested with the loop in the shielded test enclosure. The receiver cabinet was kept outside the shielded enclosure as it was found that many receivers radiated enough noise (presumably from their display drivers and digital circuitry) to seriously impair the audio measurements. However, during the testing process it was learned that a few receivers produced a spurious signal at 2.50 kHz that appeared in their distortion spectrum displays, necessitating re-measurement after experimentation with the receiver’s position outside the shielded enclosure to minimize the spurious signal. The cause of this signal was undetermined despite a recheck of off-air signal ingress and instrument shielding.
10. All receiver tests were conducted end-to-end, including audio processing. The Orban Optimod 9200 Digital AM Processor and Telos-Omnia 5EX-HD Processor were operated with standard broadcast settings for tests involving program audio. Both processors were measured to ensure that their audio performance was in accordance with their published specifications.
11. Figure M-4 shows the output signal of the Optimod 9200 as the lowpass filter is stepped from 9.5 kHz (NRSC-1 or "10 kHz" in the context of the current report) to 4.5 kHz in 500 Hz increments. This is the power spectrum at the processor's output measured according to the NRSC standard using pulsed USASI noise as a source and making a "maximum peak hold" measurement with a Hewlett Packard 3562A Dynamic Signal Analyzer. The processor was preset to GEN MEDIUM and the input levels were adjusted for 10 dB of indicated gain reduction on the processor's AGC meter. This measurement shows the effect of all audio processing (including clipping) on the output spectrum.
12. Figure M-5 shows the output signal of the Omnia 5EX-HD processor as the lowpass filter is stepped from “10 kHz” to 8, 7, 6, 5.5, and 5 kHz. Differences in the instrumentation used by Orban and Telos caused differences in the way the power spectrum of each processor was displayed.
13. The overall test bed was evaluated for amplitude linearity and distortion. Figure M-3 shows the demodulated end-to-end performance of the system using the Optimod 9200 processor for pre-emphasis (compression and limiting were disabled). All tones should register at -23.1 dB [20*log (0.7/10)].

Figure M-3 - Overall test bed spectrum using 10-tone signal at 70% total modulation (top scale)

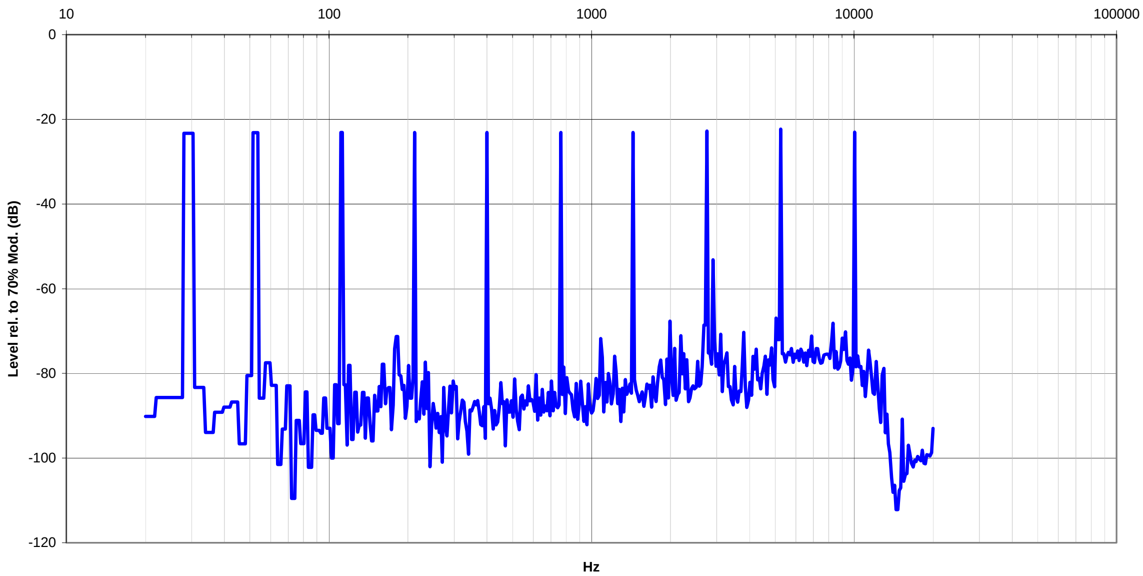


Figure M-4 - Spectral output mask of Optimod 9200 using USASI noise at lowpass filter bandwidths from 4.5 kHz to 9.0 kHz in 500 Hz increments.

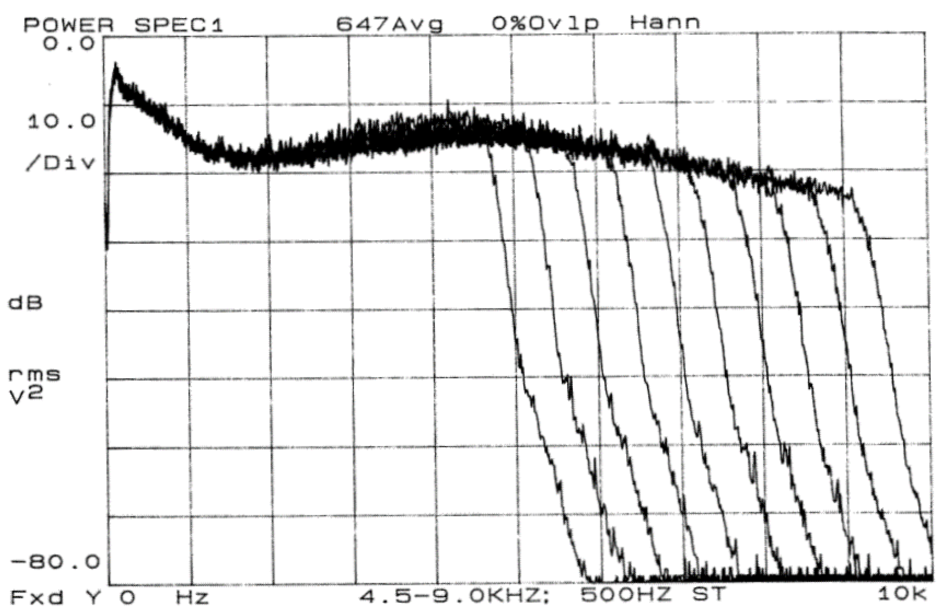


Figure M-5 - Spectral output mask of Omnia 5EX processor using USASI noise at lowpass filter bandwidths 10, 8. 7, 6, 5.5 and 5.