

*NRSC
GUIDELINE*

NATIONAL RADIO SYSTEMS COMMITTEE

NRSC-G101-A AM Modulation-Dependent Carrier Level (MDCL) Usage Guideline January 2016



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FOREWORD

Modulation-dependent carrier level (MDCL) technology offers a way for AM broadcasters to reduce their electrical power consumption with a minimum of impact on the quality of the audio signal received by listeners. In September, 2011 the Federal Communications Commission (FCC) greatly simplified the procedures for broadcasters in the U.S. to take advantage of this technology and as a result, U.S. broadcasters are more likely to embrace MDCL techniques. The purpose of this NRSC Guideline is to provide useful information to broadcasters that will assist them in the use of MDCL technology.

The information contained in this NRSC Guideline was compiled and reviewed by the MDCL Working Group, chaired by Tim Hardy, Nautel, a sub-group of the AM and FM Analog Broadcasting (AFAB) Subcommittee of the NRSC, co-chaired by Stan Salek, Hammett & Edison, Inc., and Gary Kline, Cumulus Broadcasting. The NRSC chairman at the time of adoption of NRSC-G101 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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AM MODULATION-DEPENDENT CARRIER LEVEL (MDCL) USAGE GUIDELINE

1 SCOPE

This is an informative Guideline document which provides information on modulation-dependent carrier level (MDCL) technologies available for use by AM broadcasters as a means to reduce electrical power consumption of their facilities and, when used carefully, will have little or no impact on the audio quality of their AM transmission.

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(s) or version(s) indicated were 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] *MDCL Operation is a Winner for High-Power AM*, W.C. Alexander, Radio World, April 18, 2012
- [2] *Implementation of Amplitude Modulation Companding in the BBC MF National Networks*, C.P. Bell and W. F. Williams, IEEE Transactions on Broadcasting, Vol. 35, No. 2, June 1989
- [3] *Amplitude Modulation Radio Broadcasting: Application of companding techniques to the radiated signal*, W. I. Manson, BBC Research Department, BBC RD 1985/13, November 1985
- [4] *Implementation of Amplitude Modulation Companding in the BBC MF National Networks*, C. P. Bell et. al., BBC Engineering Division Report, BBC RD 1988/15, December 1988
- [5] *An Introduction to Variable Carrier Power Systems and a Comparison of Benefits*, J. Fred Riley, Continental Electronics Corporation, May 16, 2011
- [6] *Millions Saved with MDCL*, Daniel Maxwell, Radio World Engineering Extra, April 18, 2012, pp. 1-10
- [7] *Engineering Statement – Request for Special Temporary Authority or Experimental Operation*, Kotzebue Broadcasting, Inc., KOTZ (AM), Kotzebue, Alaska, Hatfield & Dawson, May 25, 2010
- [8] *Media Bureau to Permit Use of Energy-saving Transmitter Technology by AM Stations*, FCC Public Notice, DA 11-1535, September 13, 2011 (available online at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-11-1535A1.pdf)
- [9] *Application of Modulation Dependent Carrier Level (“MDCL”) Control Technologies to Amplitude Modulation Transmission Systems*, Terry L. Cockerill, 2012 NAB BEC Proceedings
- [10] *Energy Savings with MDCL*, Daniel Maxwell, 2012 NAB BEC Proceedings
- [11] *Saving Power with AM IBOC Using Modulation-Dependent Carrier Level Control*, Brian W. Walker, 2012 NAB Proceedings
- [12] *Riley Criticizes Use of AMC*, Radio World, February 3, 2012
- [13] *ACC+ Adaptive Carrier Control Technical Manual*, Harris, August 2009
- [14] *Die Technik der Amplituden-Modulatoren*, Prof. Dr.—Ing. Dietmar Rudolph, December 15, 2009
- [15] *Electric State Profiles Map DOE/EIA-0348(01)/2*, U.S. Energy Information Administration, 2009
- [16] *Dynamic Carrier Control PWB, NAPX05E/02: Installation and Operating Instructions*, January 3, 2007
- [17] *Dynamic Carrier Control Unit, NAX154/NAPX05*, May 15, 2003

- [18] *Comparison of CCM Techniques*, J.Fred Riley, Continental Electronics Corporation, IEEE Broadcast Symposium, September 22-23, 1994
- [19] *Dynamic Carrier Control, DCC, a Valuable Method to Save Input Power of Medium Wave Transmitters*, Dr. Wolfram Schminke and Hans-Ulrich Boksberger, IEEE Transactions on Broadcasting, Vol. 35, No. 2, June 1989
- [20] *Implementation of Amplitude Modulation Companding in the BBC MF National Networks*, C. P. Bell et. al., BBC Engineering Division Report, BBC RD 1988/15, December 1988
- [21] *Energy Saving for AM Transmitters*, James Wood, *International Broadcasting*, October 1987
- [22] *Radio Engineers' Handbook*, Frederick Emmons Terman, McGraw-Hill Book Company: New York, 1943
- [23] *Phone Transmission with Voice-Controlled Carrier Power*, G.W. Fyler, QST January 1935
- [24] *Megawatt Misers*, James Wood, *International Broadcasting* magazine (date unknown)
- [25] *Adaptive Carrier Control for DX Transmitters*, Harris
- [26] *First Report and Order, Further Notice of Proposed Rule Making, and Notice of Inquiry*, FCC 15-142, MB Docket No. 13-249, Adopted October 21, 2015, Released October 23, 2015

2.3 Symbols and Abbreviations

In this Guideline the following abbreviations are used.

AM	Amplitude Modulation
ACC	Adaptive Carrier Control
AGC	Automatic Gain Control
AMC	Amplitude Modulation Companding
DAM	Dynamic Amplitude Modulation
DCC	Dynamic Carrier Control
DCS	Dynamic Carrier Systems
DSB	Double-sideband
MDCL	Modulation-dependent Carrier Level
MDCLWG	Modulation Dependent Carrier Level Working Group (of the NRSC AFAB Subcommittee)
NRSC	National Radio Systems Committee
FCC	Federal Communications Commission (U.S.)
IBOC	In-Band/On-Channel
N/A	Not Applicable
RF	Radio Frequency
TBD	To Be Determined

2.4 Definitions

In this Guideline the following definitions are used:

Amplitude Modulation Companding (AMC)

An MDCL system which operates with full carrier for no or low modulation and reduces both carrier and sidebands with increasing modulation. Typically the maximum carrier and sideband compression is adjustable between 0 and 6 dB.

Adaptive Carrier Control (ACC)

An MDCL system which operates with reduced carrier for no or low modulation and increases it with modulation. The exact characteristic may be widely adjustable.

Dynamic Amplitude Modulation (DAM)

An MDCL system similar to ACC. DAM originated in Germany in the 1980s.

Dynamic Carrier Control (DCC)

An MDCL system similar to ACC. DCC originated in Switzerland in the 1980s.

Dynamic Carrier Systems (DCS)

A general category of MDCL system characterized by operation with reduced carrier for no or low modulation and increasing carrier with modulation. Dynamic Carrier Systems include Adaptive Carrier Control, Dynamic Amplitude Modulation and Dynamic Carrier Control.

HD Radio™

Trademark (of DTS, Inc.) for the digital AM and digital FM transmission technology authorized by the FCC. Note that the use of the term in NRSC documents shall be interpreted as the generic term “IBOC” 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.

Modulation-Dependent Carrier Level (MDCL)

A system for reducing the electrical energy consumption of AM transmitters whereby either the carrier or carrier and sidebands are dynamically reduced as a function of the modulation index.

3 BACKGROUND

3.1 The Purpose of MDCL Systems

The current method of transmitting analog audio information in the medium wave broadcast band in the U.S., as well as the rest of ITU Region 2, is double-sideband amplitude modulation (DSB-AM). For this modulation technique, as the amplitude of the radio frequency (RF) signal is varied in accordance with the modulating signal, the RF carrier level remains constant while the sidebands vary in amplitude and frequency. The total power of the signal at 100 % positive and negative modulation is 50 % greater than that of the carrier. This scheme has been useful for many years because the presence of the constant-amplitude carrier allows for the use of relatively simple and inexpensive, generally diode-based, detectors in the receiver. Since modern receivers work fine with no carrier present, the carrier itself is not as critical a component of the signal as it once was, and consequently it makes sense to reduce the carrier component since a substantial portion of the energy of the transmission is contained in the carrier.

If the carrier amplitude as well as sideband amplitude are varied in accordance with the modulating signal, it is possible to provide approximately equivalent transmission service while reducing the total energy of the transmitting process. Such systems are considered “Modulation Dependent Carrier Level” systems, or MDCL systems.¹

There are two basic types of MDCL operation. The first reduces the carrier and sidebands to an arbitrary percentage of the nominal power level, and increases the carrier and sidebands with increased modulating signal level up to the nominal power level. The second only modifies the carrier level, using full carrier transmission at low modulation indices, while reducing carrier with increasing modulation level to the point where the total signal amplitude is the same as that of “full carrier.”

Each of these two methods provides benefits, in particular reduced power consumption, and are detailed below. Each has some drawbacks, which are also described below, as well as in some detail in the references listed in Section 2.2.²

3.2 The History of MDCL Systems

During the same period when high-quality, relatively efficient amplitude modulated transmission systems were developed, early recognition of the benefits of some control of carrier by modulating signal amplitude took place.³ The first known published description of such a system was in 1934, in the German journal *Physik*, by Pungs and Gerth. It is not known if tests of the proposal, named HAPUG, were conducted.

The first reported tests were undertaken by the General Electric Co. at their 50 kW medium wave broadcast station, WGY, Schenectady, New York. These were reported without detail in an article in *QST* in January, 1935. The *QST* article’s purpose was to describe a prototype method for obtaining controlled carrier with class B plate modulation. This was also reported briefly in Terman’s classic *Radio Engineer’s Handbook*.

The introduction of modern switched-carrier techniques for generating an AM modulated signal, together with the introduction of solid state high power amplification techniques in the early 1980s, led to reexamination of the possibility of use of modulation-controlled carrier methods. By 1985, modulation-controlled carrier systems were in use in several MF broadcasting stations in continental Europe and the U.K. By the end of the decade, a flurry of publications reported the success of these systems in substantially reducing electrical power consumption costs. The applications tried in continental Europe used various versions of a system called “DAM” (see Section 4.2), operating with reduced carrier for no or low modulation

¹ The term MDCL was first suggested as a non-proprietary general description of the various methods by J.F. Riley of Continental Electronics at an IEEE BTS Symposium in 1994.

² In particular, [19] and [22] discuss the pros and cons of various MDCL systems.

³ The transformer coupled high level plate modulated class C amplifier, the Doherty load-pulling amplifier, and the Chireix phase-to-amplitude system were all developed in the middle 1930’s, and first provided high quality high fidelity high power AM transmission capabilities.

and increasing carrier with increasing modulation depth. The U.K. implementations used a different system, "AMC" (see Section 4.1), in which full carrier is employed with no or low modulation and carrier is reduced with increasing modulation depth. This system was used by BBC on conventional Doherty linear amplifier transmitters as well as those employing switched modulation methods.⁴

Over the past two decades, the use of these systems by HF broadcasters has been widespread. Use of these systems by MF broadcasters has also taken place, particularly at high power installations in Europe and the Middle East where the power savings proved very attractive. By the late 1990s, MDCL techniques were essentially standard operating practice at many if not most HF transmitting stations. Within the past 10 years or so, most if not all major transmitter manufacturers have made the equipment necessary for MDCL operation available as an option and, in some cases, standard equipment with high power transmitters.

3.3 MDCL Systems Commonly in Use

Most manufacturers of modern solid state AM transmitters include optional or standard features that support MDCL operation. Additionally, upgrades for installed transmitters are also available. GatesAir (formerly Harris) supports both AMC and ACC for DX, 3DX and DAX series transmitters. Nautel NX series transmitters support MDCL as a standard feature including AMC and Dynamic Carrier Systems. Nautel also manufactures an external Dynamic Carrier Control unit for installation with earlier models. European manufacturers including Transradio and Ampegon offer support for a range of modes including AMC, DAM and DCC. Many transmitters not designed with a "built-in" MDCL capability but capable of being DC-coupled on the analog audio input would likely be able to support MDCL operation, by using an external MDCL adapter (made by various manufacturers).

3.4 Recent Developments in the United States

The U.S. government's international broadcasting agency, the Broadcast Board of Governors, which operates several high power HF and MF transmitting stations, began using various versions of MDCL systems when they became generally available in the 1980s and 1990s. By 2010 the agency had conducted studies of the relative merits of the systems, and had determined that the BBC type, AMC, provided the most benefits. The system was implemented at 19 of their transmitters, and resulted in very significant reductions in power use. [6]

At approximately the same time, Alaska Public Broadcasting, which provides technical services to public broadcasting stations throughout Alaska, became aware that costs of electrical power, supplied by diesel generators in many cases, were escalating rapidly, particularly in the remote areas of the state. FCC staff, when questioned, indicated that experimental or special temporary authority for MDCL operation would be obtainable. The Alaska agency decided to pursue the possibility of using MDCL methods to reduce these costs, and budget for the necessary tests became available in early 2010. The initial request, for KOTZ in very remote Kotzebue, was filed June 18, 2010, and granted by FCC on June 24th. [7] These tests, and subsequent tests by KDLG, Dillingham later that year, were so successful that a general request for experimental authority for all Alaska public broadcasting AM stations was filed with the FCC in March, 2011.

⁴ The two publications which provide the most succinct descriptions of these two systems are both contained in Vol. 35, No. 2, the June, 1989 IEEE Transactions on Broadcasting. They are: Bell & Williams, "Implementation of Amplitude Modulation Companding in the BBC MF National Networks," and Schminke & Boksberger, "Dynamic Carrier Control, DCC, A Valuable Method to Save Input Power of MF Transmitters."

3.5 The FCC Authorization Process

The October 2015 First Report and Order in the FCC's "AM Revitalization" Proceeding established the current procedure for stations to follow regarding use of MDCL. [26] AM stations must electronically notify the Media Bureau of the station's MDCL control operation within 10 days after commencement of such operation using FCC Form 338 – AM Station MDCL Notification, available in the CDBS Electronic Filing System.

Historically the FCC has required AM stations to operate with 5 % or less (at 100 % modulation) "carrier shift," *i.e.*, reduction (or increase) in carrier amplitude, however this rule was eliminated sometime in the 1980s.⁵ Subsequently, the principal FCC rule requiring waiver in order to operate with any of the MDCL methods was 47 CFR §73.1560(a), the rule requiring AM broadcasting stations to maintain operating power within +5/-10 % of authorized power.

Following the successful test conducted by Alaska public broadcasting stations and the March 2011 general Alaska waiver request, the Commission staff determined that a general waiver for any AM station desiring to implement MDCL was desirable. The official announcement of this policy was made on September 13, 2011. [8] The Public Notice contains a succinct explanation of the MDCL methods, refers to recent transmitter manufacturer technical data, points out that the National Radio Systems Committee (NRSC) has undertaken to study compatibility of MDCL with hybrid AM in-band/on-channel (IBOC) digital radio, and contains a caveat requiring operation with full carrier when field intensity measurements are being conducted.

The FCC also requires that the transmitter achieve full licensed power at some audio input level, or when the MDCL is temporarily disabled. This requirement will permit stations to use energy-saving MDCL technologies, which preserve licensed coverage areas, while distinguishing between such operations and simple reductions in transmitter power, which do not preserve the licensed coverage area. The FCC will permit AM stations broadcasting in hybrid AM IBOC mode to implement energy-saving MDCL technology provided the hybrid signal continues to comply with spectral emissions mask requirements in Section 73.44. Note that in the 2015 First Report and Order, the Commission noted that there are no requirements that AM stations operating in hybrid IBOC mode, using MDCL, concomitantly reduce their digital signal levels.[26]

Subsequent to the issuance of the Public Notice, a modest number of AM broadcasting stations have implemented MDCL operation. To date, all public reports from these users of MDCL have been favorable, and have noted significant electrical power savings.

3.6 Receiver Topics Overview

When the FCC initially announced that it would permit AM stations to use MDCL technologies, the initial Public Notice [8] expressed some concern about the following possible issues:

- Audio distortion
- Reduced receiver SNR
- Reduced coverage area

However, the Public Notice indicates that these effects are "generally imperceptible." Various MDCL technologies have been in use in Europe for years, and as a result there is some experience base for receiver compatibility. This experience shows that MDCL generally is acceptable or unnoticeable to the consumer. Note, however, that the European experience base generally applies only to analog AM transmission, not hybrid AM IBOC transmission. Compatibility of MDCL with hybrid AM IBOC transmissions

⁵ Within the jurisdictions of other administrations (outside of the U.S.), carrier shift rules may still be in effect.

has not yet be rigorously tested. Despite this, some points can be made about MDCL, AM analog reception and hybrid AM IBOC reception:

- In all AM systems, any change in carrier power is tracked by the receiver's AGC. If the MDCL system's rate of carrier power change is significantly slower than the AM modulation, the MDCL variations will not fall in-band to the audio AM modulation;
- Carrier power modulation is not necessarily symmetric on the attack and decay. In this context, "attack" refers to the rise of carrier power; "decay" refers to the drop in carrier power as part of the MDCL algorithm;
- At least one MDCL algorithm has a fast attack time (goes high quickly) and a relatively slow decay time (goes low more slowly);
- For IBOC reception, different algorithms have different behavior, depending on whether the IBOC subcarriers are power-modulated along with the analog carrier.

4 DESCRIPTION OF ALGORITHMS

MDCL algorithms can be classified into two categories. The first category consists of a single system, Amplitude Modulation Companding (AMC), for which both the carrier level and the sideband level are dynamically reduced together. For the second category, Dynamic Carrier Systems (DCS), only the carrier is dynamically reduced and the sideband power remains constant at the normal AM level. A number of systems fall into this category.

The performance of MDCL algorithms depends strongly on the audio source material and the audio processing. In some cases where the audio has been processed to increase the loudness levels significantly, high positive peak modulation levels may occur very regularly, i.e., many times per second. Under these conditions the MDCL algorithm may saturate (due to the fast attack - slow decay modulation detector) and the carrier power will reach a relatively static state near the 100% modulation point on the carrier compression function. For the AMC mode this behavior may be very similar to AM with reduced carrier power and for DCS modes, this behavior may be very similar to AM at full carrier power.

4.1 Amplitude Modulation Companding (AMC)

The AMC system reduce the level of the carrier and sideband together as the instantaneous audio level is increased. The degree of signal compression can vary typically from 6 dB to 1 dB with 3 dB used commonly. The exact compression functions are shown in Figure 1 for 1, 3 and 6 dB compression levels.

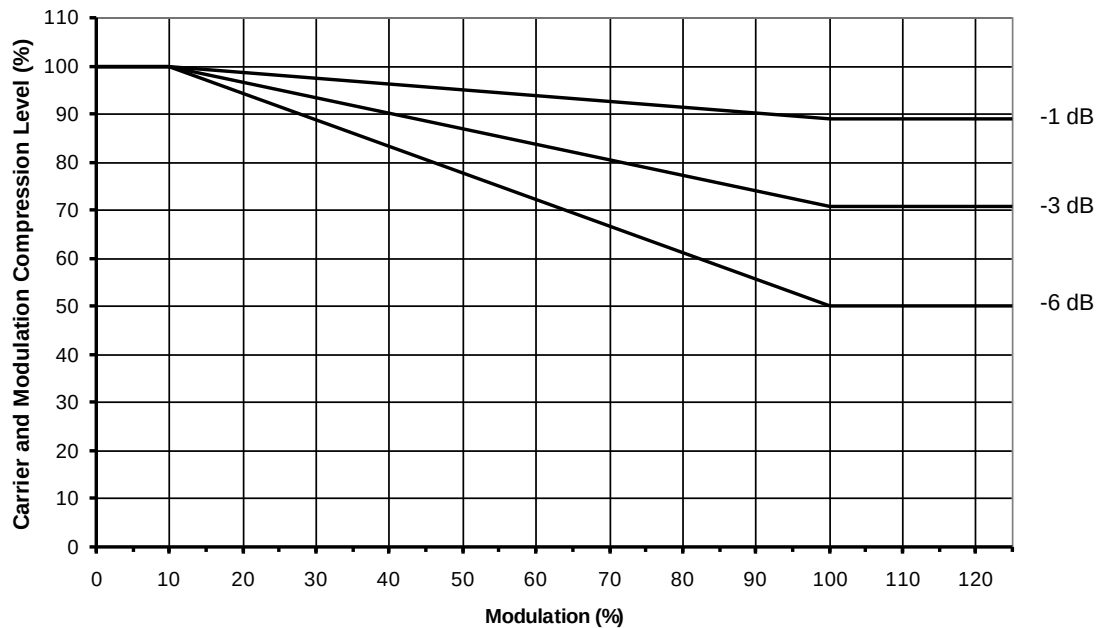


Figure 1. Amplitude Modulation Companding (AMC) compression function.

The compression characteristic is defined as follows: from 0 to 10 % modulation there is no compression (0 dB); from 10 % to 100 % modulation the compression increases linearly to full compression at 100 % modulation; from 100 % modulation to maximum peak modulation, the compression is maintained at the full level. It is important to note that the compression levels shown in Figure 1 are in voltage units and the values should be squared to determine power levels. For example, the -3 dB AMC characteristic reduces the signal to 71 % (voltage or current) at 100 % modulation and above, which is equivalent to a 50 % power reduction.

Other general characteristics of AMC include the following:⁶

- Time domain behavior: the implementation requires that different time constants are used for the attack and decay of the detected audio/modulation level;
- Attack time: the detected modulation level is increased with a fast attack time of approximately 1 ms. The filter used to implement the fast attack time is normally a simple exponential filter; however, it may be beneficial to use a finite impulse response filter that will settle more quickly for the decay implementation. A low overshoot implementation such as a Gaussian filter is recommended;
- Decay time: the detected modulation level is decreased with a slow attack time of approximately 250 ms;
- A key performance aspect of AMC systems is that there is no change in the perceived loudness of the signal. This is a consequence of the carrier and sideband levels tracking, unlike the systems which fall into the second category (DCS) where only the carrier level is being modified.

4.2 Dynamic Carrier Systems (DCS)

Generally, all systems other than AMC including Adaptive Carrier Control (ACC), Dynamic Amplitude Modulation (DAM), and Dynamic Carrier Control (DCC) fall into the DCS category. These systems reduce the carrier power dynamically but leave the transmitted sideband power unaffected, and they reduce the carrier power at low modulation levels and return the carrier to full power as modulation is increased. In general, the carrier level should never be reduced to the point where there is insufficient carrier to support negative modulation without clipping and distortion. These systems save more energy in quiet periods, as opposed to AMC which saves more energy during loud periods.

A characteristic that all systems in the DCS category share is the effect on received signal intensity which will likely impact loudness perception. In the receiver, the AGC will keep the carrier level constant. When the carrier is reduced at the transmitter, the gain at the receiver is increased causing a corresponding increase in loudness. AMC systems do not exhibit this behavior because the sidebands and carrier are always reduced together.

For DCS, time domain behavior typically has a fast attack time of 1 ms and a slow decay time of approximately 250 ms. While there are several different system names employed by manufacturers, the operation of these systems are very similar to one another with the primary differences being in the carrier compression functions. Two example systems are shown in Sections 4.2.1 and 4.2.2 below.

4.2.1 Dynamic Carrier System Example 1

In this example, the maximum carrier compression is 4 dB, between 0 and 60 % modulation (see Figure 2). Above 60 %, the carrier voltage is increased linearly to 100 % at 95 % modulation. The carrier compression between 60 % and 95 % is very close to the maximum possible compression. For example, at 70 % modulation, the carrier is compressed to approximately 74 % with 70 % being the limit. The actual modulation depth realized at this point on the curve will be very close to 100 % (the modulation depth is increased as the carrier is reduced). Below 60 % modulation, the carrier compression of 4 dB is relatively large. Overall, this example system has relatively aggressive compression characteristic resulting in relatively greater power savings.

⁶ Note that there may be some differences between implementations currently in use.

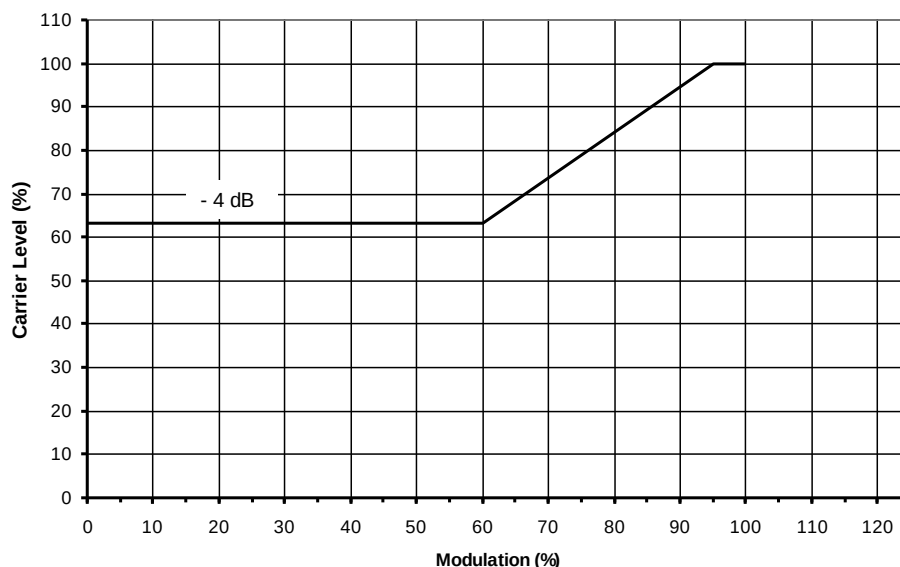


Figure 2. DCS example 1 – carrier compression function

4.2.2 Dynamic Carrier System Example 2

The carrier compression characteristic of the second example system is shown in Figure 3. This system has a maximum compression of 4.44 dB between 20 % and 40 % modulation. Below 20 % modulation, the carrier compression is reduced, with the carrier level at 80 % of its normal value during silent periods with no modulation. The reason for this increase in carrier level during quiet periods is that background noise is most perceptible when the program audio is quiet. To mitigate the increase in noise, the carrier is increased slightly. Between 40 % and 80 % modulation, the carrier is linearly increased to 100 % of its nominal value. Above 80 % modulation, the carrier remains at 100 %.

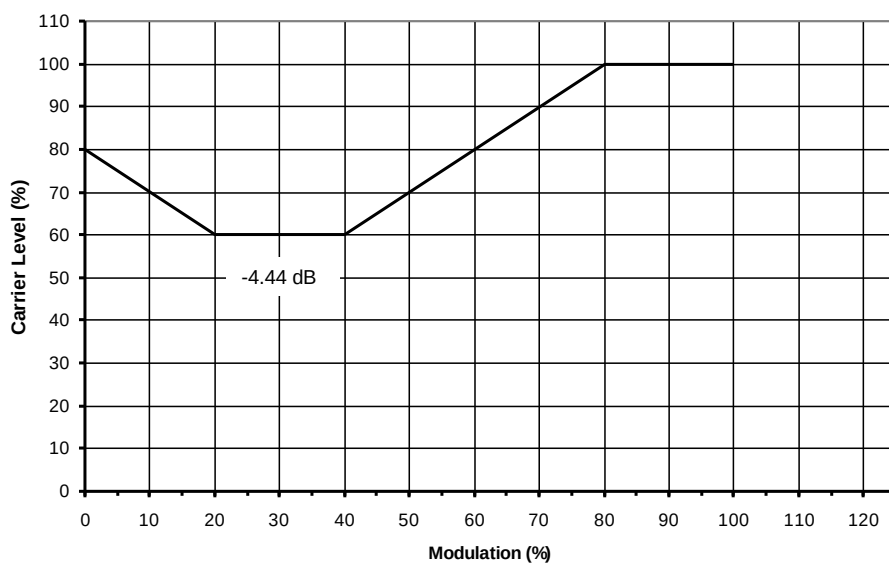


Figure 3. DCS example 2 – carrier compression function

4.2.3 Power Savings Comparison

Energy savings will vary between MDCL systems and will also be affected by the audio program material and audio processing. Table 1 shows energy savings predictions for a range of different audio samples. The performance of 1 and 3 dB AMC with the two examples of Dynamic Carrier Systems were compared to standard AM.

Table 1. Energy savings performance

MDCL Mode	Audio Source Number									
	1	2	3	4	5	6	7	8	9	10
AMC 1dB	15%	16%	16%	17%	13%	17%	17%	13%	20%	18%
AMC 3dB	37%	40%	40%	41%	32%	42%	43%	41%	48%	44%
DCS 1	16%	11%	9%	11%	27%	8%	7%	9%	2%	5%
DCS 2	23%	19%	20%	19%	41%	18%	16%	19%	4%	9%
Audio Source Legend										
1	VOA Greenville English			6	Talk - Medium Processing					
2	VOA Greenville Portuguese			7	Talk - Heavy Processing					
3	VOA Greenville Spanish			8	Music - Light Processing					
4	WYSR Talk Format			9	Music - Medium Processing					
5	Talk - Light Processing			10	Music - Heavy Processing					

A computer simulation was used to estimate the system performance indicators shown in Table 1. Audio source files, recorded after audio processing, were processed using a computer model of each algorithm and the average power levels of the modified signals were measured. The values shown in the table represent the reduction in the power of the MDCL signal as compared to the normal AM signal. While the performance of individual transmitters may vary from these estimates, it is expected that the results shown in the table are a good indication of the expected electrical energy savings of modern transmitters assuming the compression levels simulated. Note that more aggressive use of MDCL (i.e., higher levels of compression) may not result in commensurate power savings due to efficiency limitations of the transmitter.

All transmitters will have a reduction in AC to RF power efficiency as output power is reduced. For older transmitters, such as those using tube amplifiers, the low power reduction in efficiency will be more substantial than modern transmitters. For transmitters where low power efficiency is reduced more substantially, the AC power savings performance will deviate to a larger extent from the predictions in Table 1.

5 IBOC COMPATIBILITY AND RELATED ISSUES

There is a risk that the implementation of MDCL together with AM IBOC in a Hybrid IBOC system may have a negative impact on digital radio reception as compared to a non MDCL Hybrid IBOC system. To determine the effect of MDCL on Hybrid AM IBOC, the CEA and NAB commissioned a series of laboratory tests conducted at NPR Labs.

5.1 Laboratory Tests

When hybrid digital transmission (AM IBOC) is utilized, there are two “methods” in which an MDCL system may be implemented:

1. The MDCL compression has no effect on the IBOC digital subcarriers, (“Static MDCL”) or
2. The IBOC digital subcarriers are shifted in power together with the AM signal (“Dynamic MDCL”).

Different commercially-available implementations of hybrid AM IBOC / MDCL may or may not support one or the other of these approaches. The FCC’s October 2015 Report and Order to Media Bureau Docket 13-249 [26], which followed its September 2011 Public Notice [8], permits AM stations broadcasting in analog or hybrid AM IBOC modes to implement energy-saving MDCL technology without distinction of these operating modes.

Specific changes to the FCC Rules pertaining to MDCL operation adopted by the FCC in October 2015 consist of the addition of an MDCL definition and modifications to the rule pertaining to Carrier Power and Mode Tolerances to accommodate MDCL transmission, as follows:

§ 73.14 AM broadcast definitions.

Modulation dependent carrier level (MDCL) control technologies. Transmitter control techniques that vary either the carrier power level or both the carrier and sideband power levels as a function of the modulation level.

...

§ 73.1560 Operating power and mode tolerances.

(a) AM Stations. (1) Except for AM stations using modulation dependent carrier level (MDCL) control technology, or as provided for in paragraph (d) of this section, the antenna input power of an AM station, as determined by the procedures specified in § 73.51, must be maintained as near as practicable to the authorized antenna input power and may not be less than 90 percent nor greater than 105 percent of the authorized power. AM stations may, without prior Commission authority, commence MDCL control technology use, provided that within 10 days after commencing such operation, the licensee submits an electronic notification of commencement of MDCL control operation using FCC Form 338. The transmitter of an AM station operating using MDCL control technology, regardless of the MDCL control technology employed, must achieve full licensed power at some audio input level or when the MDCL control technology is disabled. MDCL control operation must be disabled before field strength measurements on the station are taken.

It must be noted that AM exciter manufacturers provide a number of ways to modulate the carrier, all falling under the general term MDCL. For the tests, a version of MDCL referred to as Amplitude Modulation Companding (AMC) was used. Figure 1, above, shows the AMC transfer functions used for these tests. Referring to the figure, during periods of 0% to 10% modulation, AMC operates with full carrier. At higher modulation, AMC reduces both carrier and sidebands up to 89% (-1 dB) or 71% (-3 dB) of full carrier. As described below, this test plan evaluated digital sideband reception of hybrid AM IBOC into various receivers and over a wide range of AM RF levels, when AMC MDCL was applied in static and dynamic modes and at 1 and 3 dB compression levels.

To measure the effect of static and dynamic AM MDCL transmission modes on IBOC digital reception, an RF test system was set up with a commercially-available hybrid AM exciter, which generates modulated AM signals for input to a broadcast transmitter. From current- or recent-model products, six consumer HD

Radio receivers were selected: two original equipment (OEM) car receivers, three after-market car receivers and one consumer table radio.

The AM IBOC exciter provided the analog and digital RF signals to the receiver under test through an attenuator and combiner system that allowed controlled levels of signal and additive white Gaussian noise (AWGN).

Because the program audio determines how MDCL controls the AM host carrier and (analog) sidebands, the type of program audio and dynamic pre-processing used were considered in the test plan. It was decided that both speech and music formats should be tested, as they have generally distinct temporal characteristics: speech having frequent silences between words and syllables, while music has more sustained sounds. A piece of popular music and a newscast were selected for the audio test material:

1. Music: "Man! I Feel Like A Woman!", Shania Twain, country vocal with guitars and drums
2. Speech: NPR studio newscast with Giles Schneider

The test audio was processed using an Orban Optimod 9300. Six presets for the Optimod were recommended by Bob Orban, covering a wide range of program density and loudness.

For more detail on the testing process and the test results, refer to the full report *Compatibility Testing of AM MDCL With Hybrid AM IBOC Waveforms On Standard Consumer and OEM Receivers*, John Kean, NPR Labs, 17 August 2015.

5.2 Test Results

The results of the testing may be summarized as follows. For static AMC MDCL as tested, the impact of compression on hybrid AM HD Radio (both Core and Enhanced modes) digital point of failure (POF) is small and may be approximated as negligible. For dynamic AMC MDCL, Core and Enhanced mode POF are degraded slightly: less than 1 dB on average in POF level for 1 dB of AMC compression, and are degraded slightly less than 3 dB in POF level for 3 dB of AMC compression.

5.3 Transmitter linearity

Modern AM solid state transmitters use two or more different methods to produce amplitude modulation. In all cases, the approach requires that the desired RF signal be separated into an audio frequency (<100 kHz) envelope and an RF frequency carrier with phase information. These two separate signals are amplified using different processes before being recombined in the RF amplifier to produce the desired RF signal. This method of amplification, Envelope Elimination and Restoration (EER), is used to improve transmitter efficiency. As a result of using the EER method, modern AM transmitter efficiencies are generally on the order of 80–90 %.

However, EER has tradeoffs which include non-linear effects that generally cause some increase in out-of-band emissions. These non-linear effects are typically made worse when antenna systems deviate significantly from ideal impedance levels. Depending on the individual transmitter and antenna system, some broadcasters may have challenges meeting the regulated emissions mask.

A key element of MDCL is that the carrier level is reduced and for the Dynamic Carrier Systems (DAM, DCC, and ACC), the modulation depth can be significantly increased. For modern AM transmitters using EER, the changes in modulation depth and reduction in carrier levels can have negative effects:

- Reducing absolute signal level will force the transmitter to spend more time operating at low levels;
- Because AM/AM and AM/PM transmitter nonlinearities generally increase as power decreases, the intermodulation levels and out of band emissions will generally increase;
- When the AM component of the signal is decreased, the bandwidth of the RF phase and envelope signals is generally increased;

- Because the amplification processes for RF phase and envelope have bandwidth limits, increasing signal bandwidths may result in an increase in intermodulation and out of band emissions.

Considering the effect that MDCL has on the signal, as well as the practical limitations of transmitter technology, caution is advised when implementing hybrid AM IBOC with MDCL. In particular, some increase in out-of-band emissions should be expected. For the same reasons outlined above, some reduction of IBOC signal quality may also be expected.

5.4 Compatibility with Nielsen Audio Portable People Meter (PPM)

In addition to working with IBOC technology, MDCL systems may also need to work with the Nielsen Audio Portable People Meter (PPM) technology which adds an inaudible “watermark” code to the transmitted audio for purposes of audience measurement.⁷

The NRSC has not conducted any tests to establish the level of compatibility of MDCL systems with the PPM system. There have been no reports of PPM issues with MDCL that the NRSC is aware of. While MDCL modifies the transmitted signal, these modifications are not significant when compared to the RF channel impairments experienced by an AM signal for which the Nielsen Audio Critical Band Encoding Technology (CBET) has been designed.

⁷ See https://en.wikipedia.org/wiki/Portable_People_Meter for information on the PPM system.

**ANNEX 1 - Compatibility Testing of AM MDCL With Hybrid AM IBOC
Waveforms on Standard Consumer and OEM Receivers**

Compatibility Testing of AM MDCL With Hybrid AM IBOC Waveforms On Standard Consumer and OEM Receivers

John Kean, Senior Technologist

17 August 2015



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Compatibility Testing of AM MDCL with Hybrid AM IBOC Waveforms on Standard Consumer and OEM Receivers

Introduction

Modulation Dependent Carrier Level (MDCL) is a technology for AM broadcasting approved by the FCC to reduce the electrical mains power consumed by the transmitter.¹ MDCL operates by reducing the AM signal power (either just the carrier or both carrier and sidebands, depending upon the algorithm) at certain modulation levels, and is implemented world-wide in several standard versions, which differ in the compression slopes and inflection points at various modulation levels.²

When hybrid digital transmission (AM IBOC) is utilized, there are two “modes” in which an MDCL system may be implemented:

1. The MDCL compression has no effect on the IBOC digital subcarriers, (“Static MDCL”) or
2. The IBOC digital subcarriers are shifted in power together with the AM signal (“Dynamic MDCL”).

This study has been conducted for and co-funded by the Consumer Electronics Association (CEA) and the National Association of Broadcasters (NAB); NAB and CEA are co-sponsors of the National Radio Systems Committee, “NRSC”). The study was designed to obtain laboratory test data to assess the impact of these two MDCL modes on the digital subcarrier reception performance of standard IBOC receivers. The NRSC’s AM and FM Analog Broadcasting (AFAB) Subcommittee has a working group on this topic, the MDCL Working Group, which provided valuable technical advice and guidance in the planning of this testing.

It must be noted that AM exciter manufacturers provide a number of ways to modulate the carrier, all falling under the general term MDCL. For the tests, a version of MDCL referred to as Amplitude Modulation Compressing (AMC) was used. Figure 1 shows the AMC transfer functions used for these tests. Referring to the figure, during periods of 0% to 10% modulation, AMC operates with full carrier. At higher modulation, AMC reduces both carrier and sidebands up to 89% (-1 dB) or 71% (-3 dB) of full carrier.³ As described below, this test plan evaluated digital sideband reception of hybrid AM IBOC into various receivers and over a wide range of AM RF levels, when AMC MDCL was applied in static and dynamic modes and at 1 and 3 dB compression levels.

¹ AM broadcast station licensees currently must obtain authority to use MDCL technologies through a request for waiver of Section 73.1560(a) of the Commission's rules (see <https://www.fcc.gov/encyclopedia/am-broadcasting-mdcl-waivers> for details).

² See National Radio System Committee, “AM Modulation-Dependent Carrier Level (MDCL) Usage Guideline”, NRSC-G101, <http://www.nrscstandards.org/sg/NRSC-G101.pdf>, April 2013, for additional information on MDCL.

³ Another method of MDCL is Dynamic Carrier Control (DCC), which reduces the carrier level during periods of either low or high audio modulation but leaves the transmitted sideband power unaffected. Both DCC and AMC were suitable for this test; however, AMC is more commonly used in the U.S. The AM exciter furnished by Nautel Corp. had modified DSP software to provide static and dynamic modes as well as adjustable transfer function settings as a test unit. All RF carrier measurements were made without analog modulation, for which AMC places the carrier at the highest level.

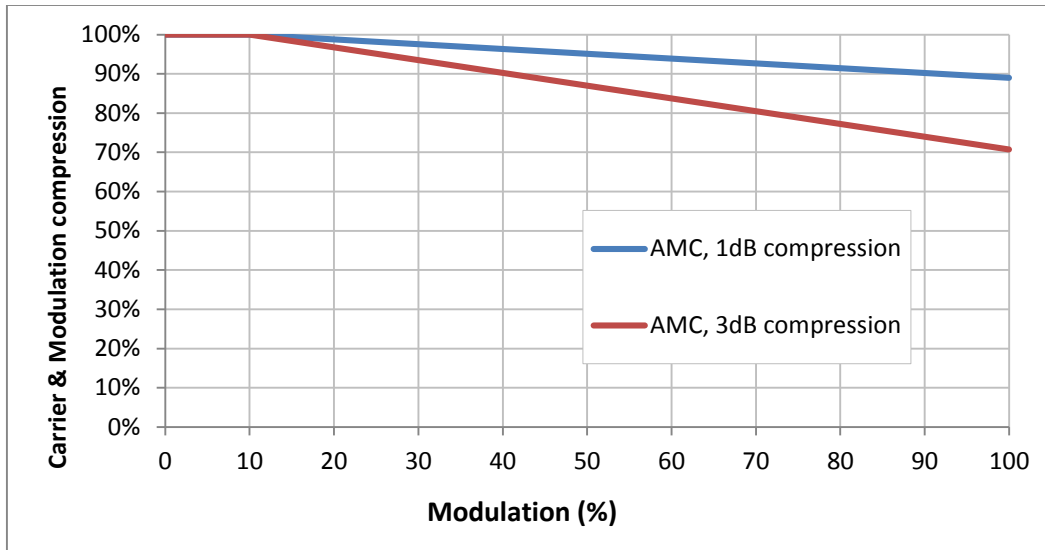


Figure 1 - Transfer functions for AMC MDCL

The results of the testing may be summarized as follows. For static AMC MDCL as tested here, the impact of compression on hybrid AM HD Radio (both Core and Enhanced modes) digital point of failure (POF) is small and may be approximated as negligible. For dynamic AMC MDCL, Core and Enhanced mode POF are degraded slightly: less than 1 dB on average in POF level for 1 dB of AMC compression, and are degraded slightly less than 3 dB in POF level for 3 dB of AMC compression.

Test System

To measure the effect of static and dynamic AM MDCL transmission modes on IBOC digital reception, an RF test system was set up with a commercially-available hybrid AM exciter, which generates modulated AM signals for input to a broadcast transmitter. From current- or recent-model products, six consumer HD Radio receivers were selected: two original equipment (OEM) car receivers, three after-market car receivers and one consumer table radio. Table 1 lists the six receivers with their approximate production year and chipset (if known).

Table 1 - IBOC AM-capable receivers used for testing

Category	Brand	Model No.	Radio Description and chipset (if known)	Year (approx.)
Automotive OEM	Delphi	28354699	FM/AM/HD (GM #22922854)	2014
	Volkswagen	RCD510	In-dash double-DIN	2013
Automotive aftermarket	JVC	KW-NT50HDT	FM-/AM/HD in-dash 1-DIN	2013
	Kenwood	KTC-BT762HD	FM-/AM/HD in-dash 1-DIN, SiLab-4763 (tuner), SiLab-4613 (HD Radio)	2015
	Sony	CEX-GT710HD	FM-/AM/HD 1-DIN	2015
Table/indoor	iBiquity/SPARC	SHD-T750	FM/AM/HD, Helio chipset	2015

The RF test system utilized is illustrated in Figure 2, and a photo of the test lab is shown in Figure 3. A Nautel AM IBOC exciter provided the analog and digital RF signals to the receiver under test through an attenuator and combiner system that allowed controlled levels of signal and additive white Gaussian noise (AWGN).

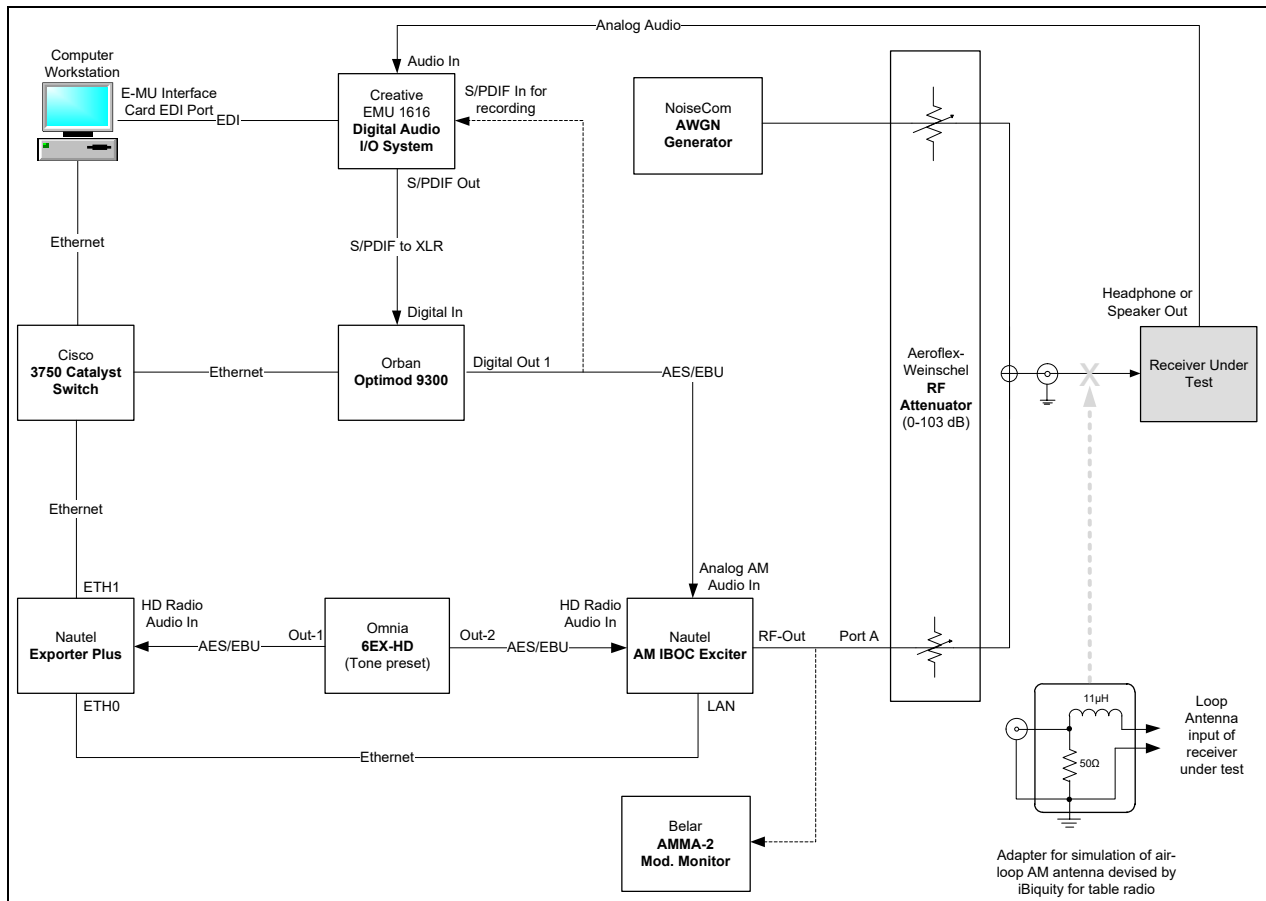


Figure 2 - RF test system used for the AM MDCL tests described in this report



Figure 3 - View of RF Lab showing the car radios (3 on cart, 2 in black display cabinet) and the iBiquity/SPARC table radio (inside the shielded test enclosure with door ajar)

Because the program audio determines how MDCL controls the AM host carrier and (analog) sidebands, the type of program audio and dynamic pre-processing used were considered in the test plan. It was decided that both speech and music formats should be tested, as they have generally distinct temporal characteristics: speech having frequent silences between words and syllables, while music has more sustained sounds. A piece of popular music and a newscast were selected for the audio test material:

1. Music: “*Man! I Fell Like A Woman!*”, Shania Twain, country vocal with guitars and drums
2. Speech: NPR studio newscast with Giles Schneider

The test audio was processed using an Orban Optimod 9300. Six presets for the Optimod were recommended by Bob Orban, covering a wide range of program density and loudness, listed in Table 2.

To expedite the testing, which required frequent changes of audio processing, the AES digital audio output of the Optimod was recorded by the EMU 1616 digital audio I/O system (shown by the dashed line in Figure 2) and stored on the hard drive of the computer workstation as a linear PCM WAV file. During testing, each audio file was streamed from a VLC Media Player playlist and back through the EMU 1616 as AES digital audio. The digital audio was run through the Optimod in bypass mode, merely as an interface (with no further change in the originally processed audio waveform) into the AM exciter.

Table 2 - Audio processing setups for program samples

Audio Sample	Processing objective	Optimod 9300 preset
Music	Light	<i>FINE ARTS</i>
	Medium	<i>MUSIC MEDIUM</i>
	Heavy	<i>MUSIC HEAVY</i>
Speech	Light	<i>FINE ARTS</i>
	Medium	<i>GENERAL PURPOSE MEDIUM</i>
	Heavy	<i>GENERAL PURPOSE HEAVY</i>

AM peak modulation was measured with a Belar AMMA-2 monitor. Modulation was set to 125% positive and 98% negative with speech and music material with the heaviest processing. Modulation limits dropped by no more than 2% with the least processing.

The RF spectrogram in Figure 4 shows an unmodulated AM test signal as the center “spike,” at 1000 kHz. This picture shows the spectrum over a range of 40 kHz, or ± 20 kHz about the carrier. The level segments nearest to the AM carrier are the Tertiary IBOC digital sidebands, which are shouldered by a pair of Secondary sidebands and farthest away, the Primary sidebands. Each digital sideband group consists of a large number of OFDM subcarriers that are too close together to resolve individually at this scale.

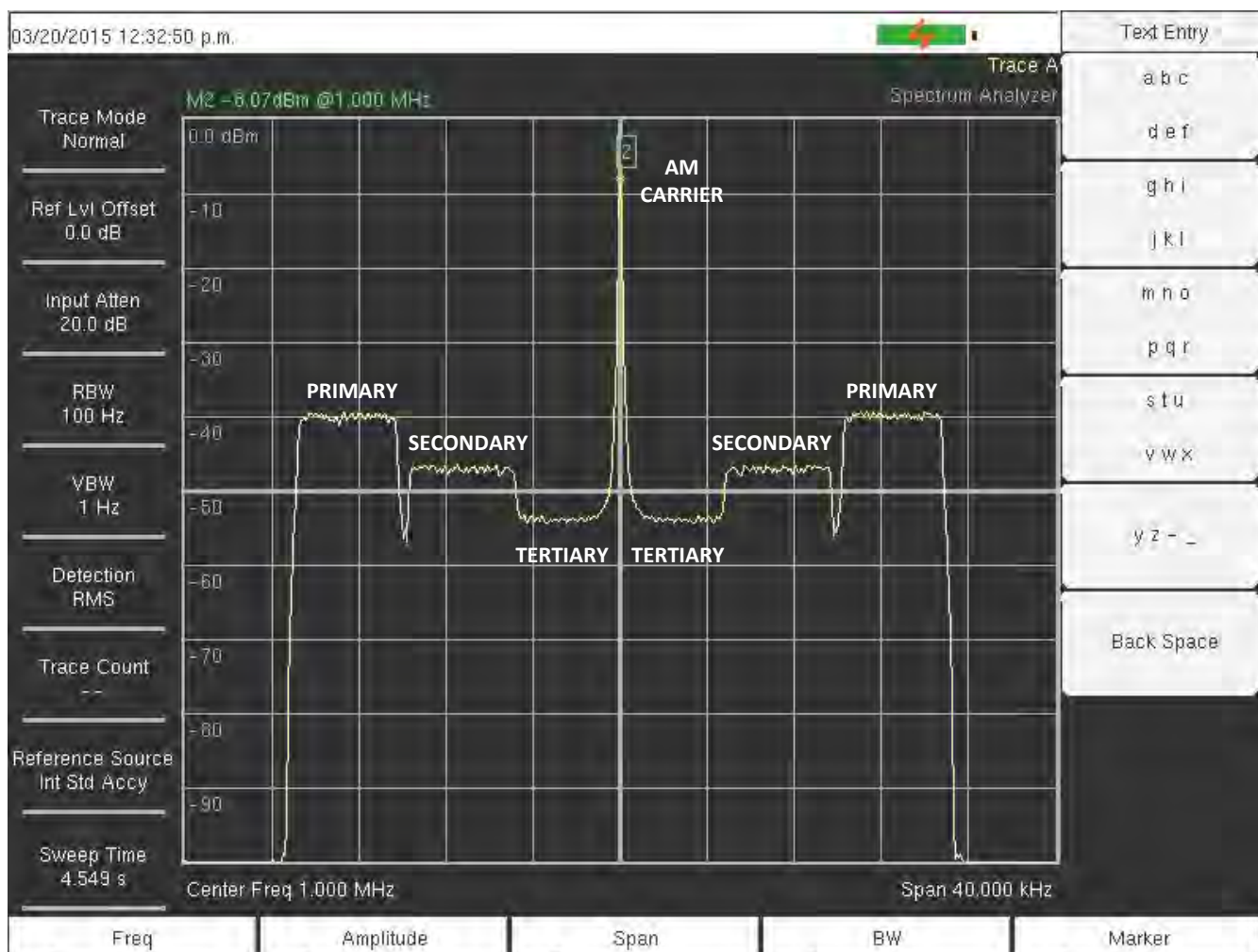


Figure 4 - RF spectrum of AM test signal with IBOC digital sidebands

Receiver Signal Input

Automotive receivers typically have unbalanced, shielded connectors for their antenna input and metal cases; the input is typically high-impedance. The shielding provided by the units used in these tests allowed for direct connection to the RF test bed using double-shielded coax. The iBiquity/SPARC table radio, however, typically uses an external loop antenna for AM, connected through a 2-wire jack on the back of the radio. For use in the test bed, a signal adapter was supplied by iBiquity, which uses a series 11 μH choke to simulate the antenna's inductance, shown schematically in the lower right of Figure 2. To avoid pickup of local broadcast signals and electrical RF noise through the case or antenna connector, the table radio was tested in a shielded test enclosure providing more than 90 dB of isolation, seen in Figure 3. Signals and mains power from test bed are passed through bulkhead connectors on the side of the enclosure.

Recent co-channel interference tests of receiver performance of all-digital AM radio, conducted by NAB Labs, used RF desired signal input levels of -48 dBm and -62 dBm, representing “strong” and “moderate” signal conditions, respectively. The values are not associated with any particular field strength contours, but were recommended by the NRSC’s MDCL Working Group for these tests. A “weak” signal level was added, determined by an RF level 6 dB greater than the IBOC digital sideband reception threshold for each receiver.⁴

⁴ Some of the car radios were designed to use an external buffer amplifier in the antenna. They are believed to be low in gain, but were unavailable for the tests and the effect of these units on sensitivity is unknown.

All tests were performed at an AM carrier frequency of 1000 kHz. For automotive receivers, the AM RF signal levels are referenced to a 50-ohm load at the receiver's high-impedance antenna connector. For the table radio, AM RF signal levels are referenced to a 50-ohm load at the input to the adapter for the table radio. IBOC digital sideband levels were set in accordance with NRSC specifications and Tertiary carrier levels were set at the manufacturer's "low" setting.⁵ All RF levels were set with RF attenuators having 1 dB steps. Therefore, the closest value reported for any RF level was ± 0.5 dB, and the resolution for any result, such as a receiver POF, was 1dB.

Test Procedure, Establishing Reference Values

To obtain reference data for the IBOC compatibility tests to follow, digital reception measurements using non-MDCL AM signals were made using the steps shown in Table 3.⁶ Step 2-1 established the IBOC POF at minimum RF level, D_{min} . In Step 2-2, the weak signal level was set 6 dB above D_{min} and then the AWGN level was raised to the point at which POF occurred, and the noise power was noted.⁷

Table 3 - Reference measurements of hybrid IBOC point of failure (POF) without MDCL

Step	Analog modulation	MDCL mode	AM RF level adjustment	AWGN adjustment	Measurement result	Audio SNR (modulation on)
2-1-1,2	OFF (-1) and with heavily-processed talk (-2)	OFF	Reduce until POF	OFF	RF level in dBm, D_{min} (MDCL off)	Yes
2-2-1,2		OFF	Set to 6 dB above D_{min} in Step 1	ON, raise until POF	AWGN in dBm/Hz for weak signal ($D_{min} + 6$ dB)	Yes
2-3-1,2		OFF	Set to -62 dBm	ON, raise until POF	AWGN in dBm/Hz for medium signal	Yes
2-4-1,2		OFF	Set to -48 dBm	ON, raise until POF	AWGN in dBm/Hz for strong signal	Yes

All steps in Table 3 were measured with and without analog modulation, that is, with and without input analog audio to modulate the carrier. To record that data in the results tables (in the Appendices and below), a "-1" was appended to each step without modulation and a "-2" was appended for each with modulation. An example of the measurement for Step 2-1 is shown in Table 4. This is taken directly from the results for the iBiquity/SPARC receiver data in Appendix A.

At the start of testing, it was realized that the POF test would measure performance of the IBOC Core mode of reception, which provides for a lower bitrate monophonic audio play out. The IBOC Enhanced mode, on the other hand, utilizes a higher quality stereo audio play out, and the system design insures that the enhanced mode signal will fail at higher signal levels than does the Core mode signal. By listening for the "blend to stereo" point as RF level is increased (from Core mode POF) it was possible to determine the enhanced mode POF and thus, the receiver result tables include a column for the Enhanced mode POF as well as Core mode POF, as illustrated in Table 4. According to this data, the Enhanced

⁵ National Radio Systems Committee, "HD Radio™ AM Transmission System Specifications, Rev. E", Jan. 2008.

⁶ Consumer receivers do not offer a measure of uncorrected bit error ratio, thus, it is necessary to rely on audio decoded by IBOC circuitry to determine POF. Specifically, a continuous audio tone is placed on the IBOC digital audio channel which is then monitored for silence, indicating digital reception failure. Note that either no modulation or heavily-processed talk modulation was placed on the analog audio channel, so during this test simulcasting was not done.

⁷ The carrier-to-noise ratio at which digital reception failure occurs will be determined by measuring signal power of the AM carrier, relative to the noise in a 20 kHz bandwidth using the channel power feature of a digital spectrum analyzer, absent the AM carrier and digital sidebands.

mode for the iBiquity/SPARC receiver required approximately 10 dB more RF level than the Core mode, which is typical of the receivers tested.

Table 4 –Results for steps 2-1 for the iBiquity/SPARC receiver

Step	Analog Modulation	MDCL Mode	D _{min} - Core Mode POF (dBm)	AWGN level (dBm /Hz)	D _{min} - Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)*	Enhanced Mode Mod - No-Mod (delta dB)
2-1-1	OFF	OFF	-92.5	"OFF"	-82.5	-10	-
2-1-2	Talk, heavily-processed		-92.5	"OFF"	-82.5	-10	0

* The minus (-) indicates that enhanced mode POF was at a higher signal level than Core mode POF

Table 4 shows the minimum RF levels at Core and Enhanced mode POF (“D_{min}”) with analog modulation off and with heavily-processed talk modulation included as the second row and labeled Step 2-1-2 (no RF AWGN in either case). Comparing the results in the first two rows of each column, it is apparent that the IBOC digital sideband reception POF of this receiver was substantially unaffected by analog modulation. This again was typical of the receivers tested.

The data is measured and reported differently for steps 2-2, 2-3 and 2-4, which are intended to determine the AWGN level at which IBOC reception POF occurs for various AM RF levels. In this test design, it was expected that at higher AM RF levels and in the absence of RF noise, MDCL alone would have little effect on IBOC reception. RF noise, however, is a common element of AM reception and provides a means of determining the impact of MDCL on IBOC reception under more typical receiving conditions.

Table 5 shows an example of the results for the iBiquity/SPARC table radio for steps 2-2, 2-3 and 2-4 (all without MDCL, results taken from Appendix A). The Core mode RF level (that is, the RF level used for establishing the Core mode POF with AWGN) for step 2-2 is 6 dB above the D_{min} determined in Step 2-1 (as shown in Table 3); the Core mode RF levels for steps 2-3 and 2-4 are set to -62 and -48 dBm, respectively. The AWGN level was adjusted in these tests to determine the point at which POF occurs with the Core mode RF level.

Table 5 –Results for Core and Enhanced mode measurements without MDCL

Step	Analog Modulation	MDCL Mode	Core Mode RF level (dBm)	AWGN level at Core Mode POF (dBm/Hz)	Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)*	Enhanced Mode Mod - No-Mod (delta dB)
2-2-1	OFF	OFF	-86.5	-153.8	-76.5	-10	-
2-2-2	Talk, heavily-processed		-86.5	-154.8	-77.5	-9	1
2-3-1	OFF		-62.5	-128.8	-52.5	-10	-
2-3-2	Talk, heavily-processed		-62.5	-128.8	-51.5	-11	-1
2-4-1	OFF		-48.5	-115.8	-37.5	-11	-
2-4-2	Talk, heavily-processed		-48.5	-115.8	-39.5	-9	2

* The minus (-) indicates that enhanced mode POF was at a higher signal level than Core mode POF

The Enhanced mode POF results shown in Table 5 were determined by raising the AM RF level *without* changing the AWGN until enhanced mode POF was reached, as determined by monitoring for stereo audio from the IBOC receiver. The column to right displays the difference, in dB, between the RF levels

at Enhanced and Core mode POF for a given amount of AWGN. The last column displays the difference in Enhanced mode POF, in dB, between heavily-processed talk modulation and modulation off.

Test Procedure, MDCL Conditions

Figure 5 shows a simplified version of the test procedure used with MDCL. The AWGN levels measured for each receiver at the IBOC POF condition with non-MDCL hybrid AM transmissions are used with AM MDCL to determine whether a change in AM RF signal level is required for IBOC POF. The same AWGN level is used for the Core and Enhanced mode tests.



Figure 5 - Flowchart of basic measurement steps for MDCL compatibility tests

The change in AM RF level, if any, represents the impact of MDCL on IBOC reception. This test procedure is repeated for each receiver for both static and dynamic MDCL, at three AM RF signal levels, and with different AM modulation conditions. During the course of testing, determination of the Enhanced mode POF of IBOC reception was added, providing additional data for four out of six receivers.

Table 6 shows the test procedure that is similar to Steps 2-1 through 2-4, for a series of MDCL modes. With each MDCL mode and modulation condition, the AM RF level were set sufficiently above the values discovered in Steps 2-1 through 2-4, with audio program content and processing specified in Table 7. The AM RF level was decreased until the POF with MDCL is determined. The intention was to determine the change in AM RF level, if any (and the relative change in associated AWGN, if any) for POF when various MDCL modes are introduced compared to the cases with no MDCL.

Table 6 - Conditions for MDCL compatibility test

Step	Analog Modulation	MDCL mode	AM RF level adjustment	AWGN adjustment	Measurement result
3-1	As specified in Table 7 (6 AM audio processing conditions for each MDCL case)	ON	Reduce until POF, note RF level	OFF	RF level in dBm, Dmin (MDCL on)
3-2		ON	Initially, set above RF value in Step 2-1, decrease until POF	ON, set to same power in Step 2-2 (w/modulation)	RF level, dBm
3-3		ON	Initially, set above -62 dBm, decrease until POF	ON, set to same power in Step 2-3 (w/modulation)	RF level, dBm
3-4		ON	Initially, set above -48 dBm, decrease until POF	ON, set to same power in Step 2-4 (w/modulation)	RF level, dBm

Table 7 illustrates the proposed matrix for the audio content and processing (discussed earlier) for the MDCL tests. All of the tests in Table 6 were conducted for each of the numbered cells in Table 7. Both static and dynamic MDCL modes are tested with compression settings of 1 dB and 3 dB. (The numbering in the boxes is used in the step sequence for the tables that are discussed next.)

Table 7 - Test matrix of MDCL modes and audio processing

MDCL mode	MDCL compression (dB)	Audio processing level and content type					
		Light		Medium		Heavy	
		Talk	Music	Talk	Music	Talk	Music
Static	1	1	1	1	1	1	1
	3	2	2	2	2	2	2
Dynamic	1	3	3	3	3	3	3
	3	4	4	4	4	4	4

There were 96 conditions (4 MDCL step conditions from Table 6 times 24 sub-steps from Table 7) tested in the Core mode for each of the six receivers. The same 96 conditions are included for the iBiquity/SPARC table radio and Delphi, JVC, and Kenwood car radios in the Enhanced mode. The essential test data for each receiver is reported in the tables in Appendix A through Appendix F as indicated in Table 8.

Table 8. List of data tables in Appendices

Test	DATA TABLE IN APPENDICES					
	RECEIVER					
	iBiquity/SPARC	Delphi (OEM)	Sony	VW (OEM)	JVC	Kenwood
Determination of D_{min} for Core and enhanced modes	A-1	B-1	C-1	D-1	E-1	F-1
Results for Core and Enhanced mode measurements without MDCL	A-2	B-2	C-2	D-2	E-2	F-2
Change in Core mode POF with MDCL vs. no MDCL with no analog modulation	A-3	B-3	C-3	D-3	E-3	F-3
Change in Core mode POF with MDCL vs. no MDCL with talk-heavy processing	A-4	B-4	C-4	D-4	E-4	F-4
Change in Enhanced mode POF with MDCL vs. no MDCL with no analog modulation	A-5	B-5			E-5	F-5
Change in Enhanced mode POF with MDCL vs. no MDCL with talk-heavy processing	A-6	B-6			E-6	F-6

Table 9 is a sample of the data from the iBiquity/SPARC radio with MDCL (taken from Appendix A). The step numbers follow Table 6, with the addition of the four sub-steps from each column in Table 7. The particular MDCL mode, amount of MDCL compression, and the AWGN level are shown for reference.

Table 9 - Core mode POF results with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	0	-1	0	0	0	0.0
3-1-2	Static	3	"OFF"	0	0	0	0	0	0	0.0
3-1-3	Dynamic	1	"OFF"	0	0	-1	-1	-2	-1	-0.8
3-1-4	Dynamic	3	"OFF"	-2	-2	-2	-3	-5	-3	-2.8
3-2-1	Static	1	-106.5	1	1	1	1	1	1	1.0
3-2-2	Static	3	-106.5	1	1	1	1	1	1	1.0
3-2-3	Dynamic	1	-106.5	1	1	1	-1	0	-2	0.0
3-2-4	Dynamic	3	-106.5	0	-1	-2	-2	-2	-1	-1.3
3-3-1	Static	1	-80.5	0	0	0	0	0	0	0.0
3-3-2	Static	3	-80.5	1	0	1	0	0	0	0.3
3-3-3	Dynamic	1	-80.5	0	-1	0	-1	0	-1	-0.5
3-3-4	Dynamic	3	-80.5	-1	-2	-2	-2	-3	-3	-2.2
3-4-1	Static	1	-67.5	0	0	1	0	0	1	0.3
3-4-2	Static	3	-67.5	1	1	0	1	2	0	0.8
3-4-3	Dynamic	1	-67.5	0	-1	1	0	0	0	0.0
3-4-4	Dynamic	3	-67.5	-1	-1	0	-1	-1	-1	-0.8

Notes: Tertiary Carriers set to LOW; "OFF" is AWGN at -155.8 dBm/kHz

In Table 9, the numbers in the columns to the right indicate the change in RF level (in dB) for IBOC POF with MDCL relative to the no MDCL AM reference test value, for a particular audio type and processing. A negative value means that MDCL required a higher RF level for POF than did the no MDCL case, which represents a degradation in POF. Some positive values appear in these results, indicating that the POF with MDCL occurred at a lower RF level than with no MDCL (representing a digital performance improvement).

Audio SNR Measurement

The analog audio noise level versus RF level was measured for one of the receivers, the Kenwood KDC-BT762HD, which was one of the more-sensitive automotive radios. The data below is summarized from Table F-7 for this unit at the four RF levels determined for Core mode POF, as defined by steps 2-1 through 2-4 (where -47.6 dBm and -61.6 dBm represent the strong and medium signals, and -99.6 dBm and -93.6 dBm are the threshold and threshold-plus-6 dB signals for Core mode reception).

Table 10 - Audio noise versus RF level for Kenwood car radio (without IBOC)

RF level (dBm)	Audio out (VRMS)	WQPSNR (dB)
-47.6	0.296	60
-61.6	0.295	48
-93.6	0.303	20
-99.6	0.306	17

The results show a high psophometric (weighted quasi-peak) signal-to-noise ratio for a strong signal, which decreases almost equally to the drop in RF level, to a medium signal. The two lowest RF signals resulted in noise levels that would be generally unlistenable. This overall behavior was representative of the other receivers tested.

Test Results in Summary

A set of charts were prepared to make the test results more meaningful, using average values so as to show trends and minimize the less meaningful variations between individuals tests. These charts, presented below, are based on the same arrangement of data as the tables for individual receivers in the Appendices, but average the corresponding data for all receivers together in bar graph form. The chart data is indexed by step number, MDCL mode (static or dynamic), MDCL compression level (1 dB or 3 dB), and RF level as discussed earlier. The chart data is organized with the static MDCL mode on the left half and dynamic MDCL mode on the right half. Each of those halves are further split with 1 dB MDCL compression on the left side and 3 dB MDCL compression on the right side. Each of those subsections contains four bars, which are arranged in order of RF level: minimum (*i.e.*, D_{min}), low, medium and high.

An analysis of the effects of different audio processing and different audio formats (voice and music) on IBOC POF with and without MDCL showed minimal differences across these variables. Therefore, the following charts combine all audio modulation types. Due to variability in the performance of receivers and the measurement process, it is expected that differences of less than 0.5 dB are not significant.

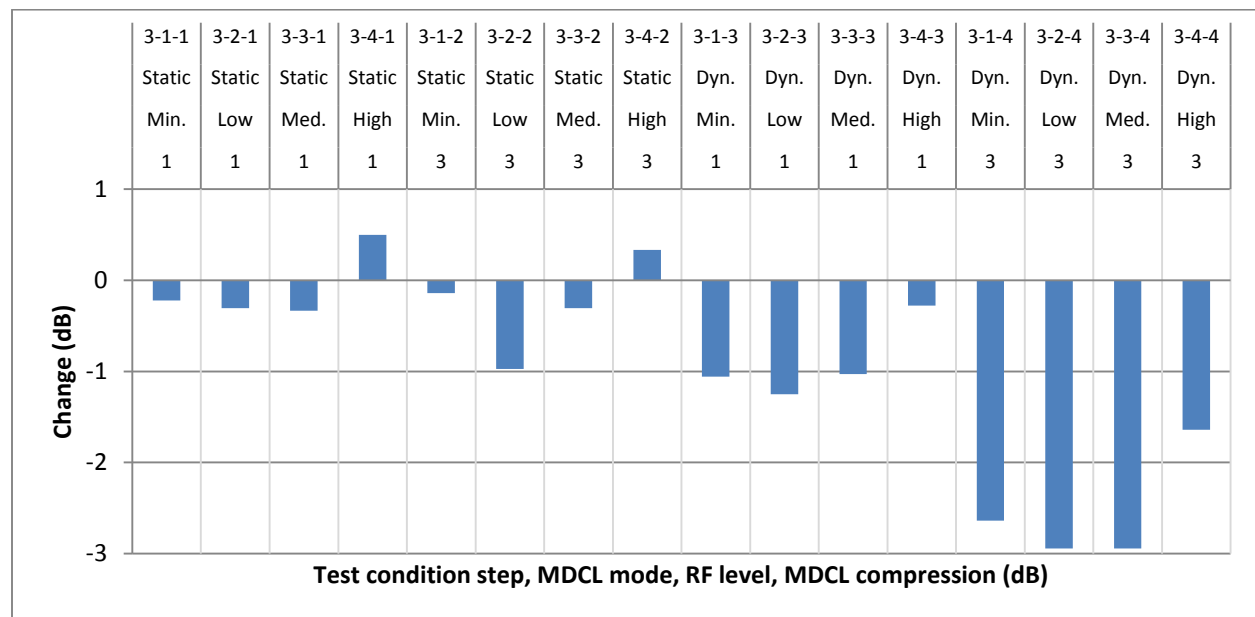


Figure 6 - Change in Core mode POF of MDCL relative to no MDCL and no AM modulation, average of six receivers (dB) – negative numbers represent a degradation in POF

The chart in Figure 6 shows how the signal requirement for Core mode POF with MDCL compares to a no MDCL and no AM modulation condition, for all receivers. Looking at the first four bars to the left, the operation of static MDCL with 1 dB MDCL compression produced no meaningful change in IBOC POF from non-MDCL AM. For 3 dB MDCL compression, in the next four bars, the data indicate a slightly more negative trend, but much less than 1 dB of impact due to MDCL. With dynamic MDCL with 1 dB MDCL compression, the effects increase to approximately 1 dB of impact overall. Finally, with 3 dB of dynamic MDCL compression the degradation in POF increases to nearly 3 dB in two cases and nearly 2.5 dB across the range of RF signal levels. Another apparent trend is that the impacts are smaller in all four scenarios for the strongest (high) RF levels.

In the next chart, Figure 7, the POF for Core mode with MDCL is compared to non-MDCL AM modulated with heavily-processed talk. These results bear a close resemblance to the results in Figure 6.

This includes the effect that high RF levels tend to reduce the impact of all modes of MDCL on IBOC receive POF.

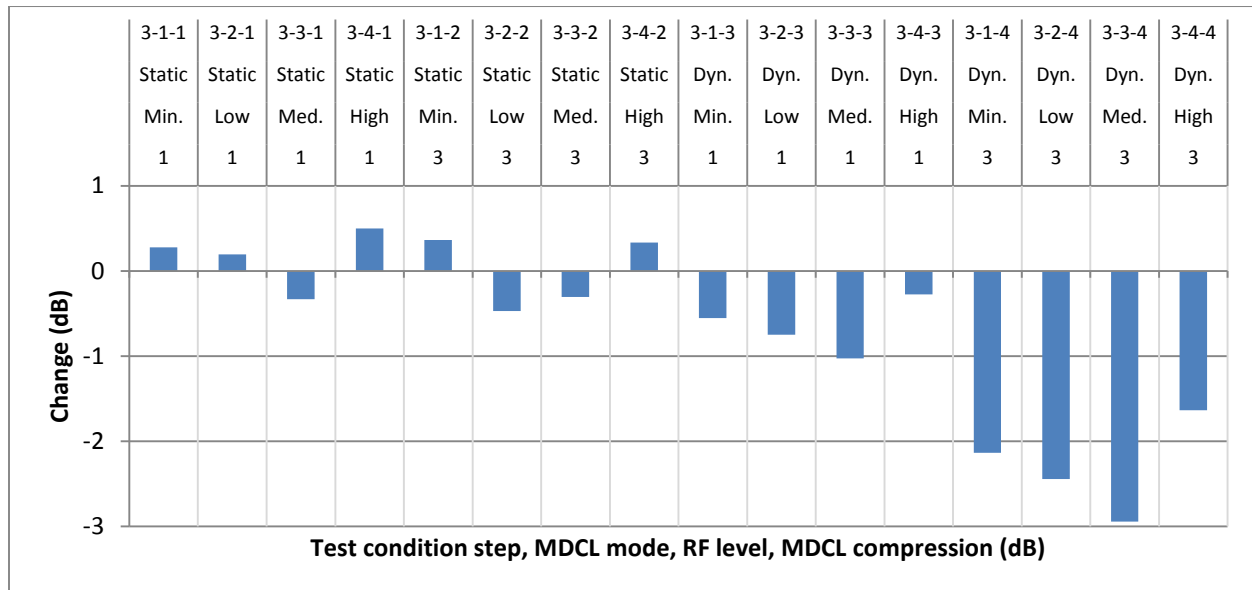


Figure 7 - Change in Core mode POF of MDCL relative to no MDCL and talk-heavy AM modulation, average of six receivers (dB) – negative numbers represent a degradation in POF

In the last two charts, the data is aggregated for the four receivers tested in Enhanced IBOC mode. Figure 8 shows the effect of MDCL on POF relative to the no MDCL and no-AM modulation condition. The POF results follow the corresponding Core mode results in Figure 6 in both trends and magnitude.

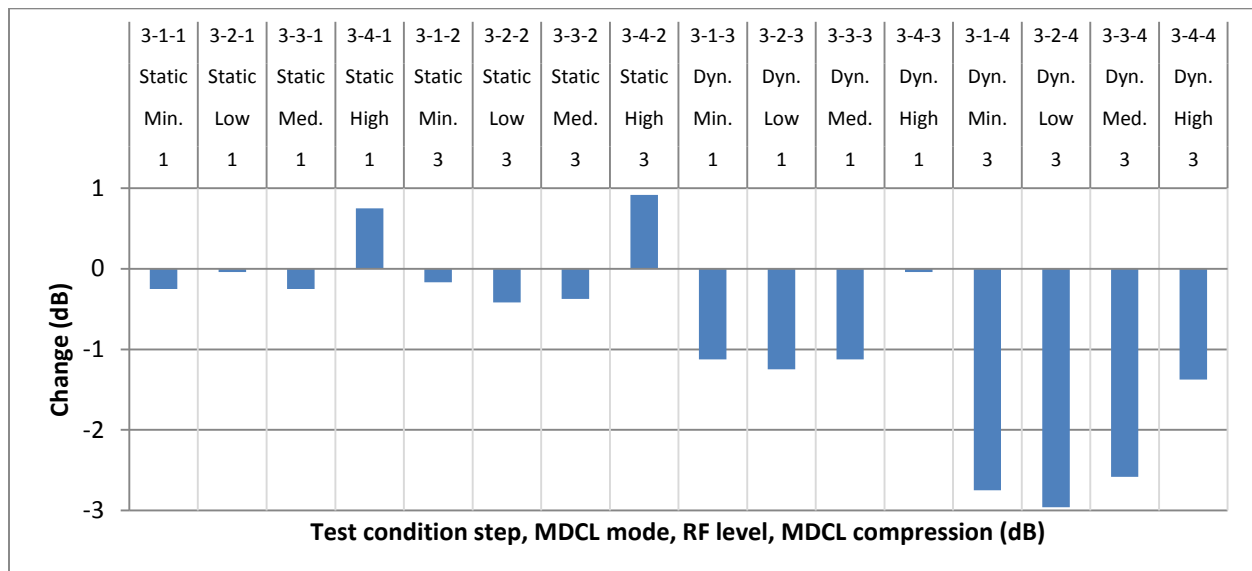


Figure 8 - Change in Enhanced mode POF of MDCL relative to no MDCL and no AM modulation, average of four receivers (dB) – negative numbers represent a degradation in POF

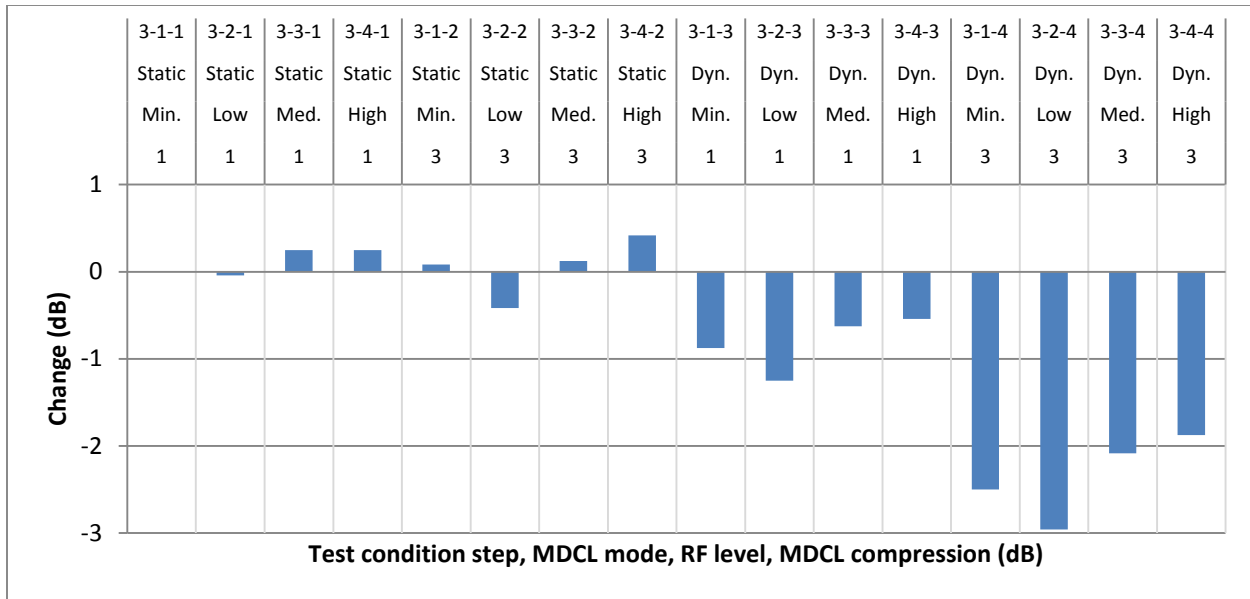


Figure 9 - Change in Enhanced mode POF of MDCL relative to no MDCL and talk-heavy AM modulation, average of four receivers (dB) – negative numbers represent a degradation in POF

The final chart, Figure 9, shows the results in Enhanced mode IBOC digital sideband reception with MDCL in comparison to no MDCL modulated with heavily-processed talk. The effects repeat the Core mode findings, in that static mode MDCL has no significant impact on IBOC reception at either compression level, while dynamic MDCL with 1 dB compression requires approximately 1 dB more receive signal, while 3 dB compression requires between 2 dB and 3 dB greater signal for POF.

Appendix A – iBiquity/SPARC SHD-T750 Table Radio Test Data

Table A-1 – Determination of D_{min} for Core and Enhanced modes

Step	Analog Modulation	MDCL Mode	D _{min} - Core Mode POF (dBm)	AWGN level (dBm/Hz)	D _{min} - Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-1-1	Off	OFF	-92.5	“OFF”	-82.5	-10	-
2-1-2	Talk, heavily-processed		-92.5	“OFF”	-82.5	-10	0
Note: “OFF” is AWGN at -155.8 dBm/kHz							

Table A-2 – Results for Core and Enhanced mode measurements without MDCL

				AWGN level at Core Mode POF			Enhanced Mode Mod - No-Mod
Step	Analog Modulation	MDCL Mode	Core Mode RF level (dBm)	(dBm/Hz)	Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	(delta dB)
2-2-1	Off	OFF	-86.5	-153.8	-76.5	-10	-
2-2-2	Talk, heavily-processed		-86.5	-154.8	-77.5	-9	1
2-3-1	Off		-62.5	-128.8	-52.5	-10	-
2-3-2	Talk, heavily-processed		-62.5	-128.8	-51.5	-11	-1
2-4-1	Off		-48.5	-115.8	-37.5	-11	-
2-4-2	Talk, heavily-processed		-48.5	-115.8	-39.5	-9	2
Note: “OFF” is AWGN at -155.8 dBm/kHz							

Table A-3 – Change in Core mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (Db)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	0	-1	0	0	0	0.0
3-1-2	Static	3	"OFF"	0	0	0	0	0	0	0.0
3-1-3	Dynamic	1	"OFF"	0	0	-1	-1	-2	-1	-0.8
3-1-4	Dynamic	3	"OFF"	-2	-2	-2	-3	-5	-3	-2.8
3-2-1	Static	1	-106.5	1	1	1	1	1	1	1.0
3-2-2	Static	3	-106.5	1	1	1	1	1	1	1.0
3-2-3	Dynamic	1	-106.5	1	1	1	-1	0	-2	0.0
3-2-4	Dynamic	3	-106.5	0	-1	-2	-2	-2	-1	-1.3
3-3-1	Static	1	-80.5	0	0	0	0	0	0	0.0
3-3-2	Static	3	-80.5	1	0	1	0	0	0	0.3
3-3-3	Dynamic	1	-80.5	0	-1	0	-1	0	-1	-0.5
3-3-4	Dynamic	3	-80.5	-1	-2	-2	-2	-3	-3	-2.2
3-4-1	Static	1	-67.5	0	0	1	0	0	1	0.3
3-4-2	Static	3	-67.5	1	1	0	1	2	0	0.8
3-4-3	Dynamic	1	-67.5	0	-1	1	0	0	0	0.0
3-4-4	Dynamic	3	-67.5	-1	-1	0	-1	-1	-1	-0.8
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix A – iBiquity/SPARC SHD-T750 Table Radio Test Data

Table A-4 – Change in Core mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	0	-1	0	0	0	0.0
3-1-2	Static	3	"OFF"	0	0	0	0	0	0	0.0
3-1-3	Dynamic	1	"OFF"	0	0	-1	-1	-2	-1	-0.8
3-1-4	Dynamic	3	"OFF"	-2	-2	-2	-3	-5	-3	-2.8
3-2-1	Static	1	-106.5	1	1	1	1	1	1	1.0
3-2-2	Static	3	-106.5	1	1	1	1	1	1	1.0
3-2-3	Dynamic	1	-106.5	1	1	1	-1	0	-2	0.0
3-2-4	Dynamic	3	-106.5	0	-1	-2	-2	-2	-1	-1.3
3-3-1	Static	1	-80.5	0	0	0	0	0	0	0.0
3-3-2	Static	3	-80.5	1	0	1	0	0	0	0.3
3-3-3	Dynamic	1	-80.5	0	-1	0	-1	0	-1	-0.5
3-3-4	Dynamic	3	-80.5	-1	-2	-2	-2	-3	-3	-2.2
3-4-1	Static	1	-67.5	0	0	1	0	0	1	0.3
3-4-2	Static	3	-67.5	1	1	0	1	2	0	0.8
3-4-3	Dynamic	1	-67.5	0	-1	1	0	0	0	0.0
3-4-4	Dynamic	3	-67.5	-1	-1	0	-1	-1	-1	-0.8
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Table A-5 – Change in Enhanced mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	2	1	2	2	2	1.7
3-1-2	Static	3	"OFF"	1	1	1	1	2	2	1.3
3-1-3	Dynamic	1	"OFF"	1	0	1	0	1	0	0.5
3-1-4	Dynamic	3	"OFF"	0	-1	-1	-2	-1	-1	-1.0
3-2-1	Static	1	-106.5	2	2	2	2	2	2	2.0
3-2-2	Static	3	-106.5	2	2	2	2	2	2	2.0
3-2-3	Dynamic	1	-106.5	1	1	1	1	1	0	0.8
3-2-4	Dynamic	3	-106.5	0	-1	-1	-1	-1	-1	-0.8
3-3-1	Static	1	-80.5	1	1	1	1	1	1	1.0
3-3-2	Static	3	-80.5	2	1	1	1	0	1	1.0
3-3-3	Dynamic	1	-80.5	1	0	1	0	0	0	0.3
3-3-4	Dynamic	3	-80.5	-1	-1	-1	-2	-2	-1	-1.3
3-4-1	Static	1	-67.5	2	3	3	3	2	3	2.7
3-4-2	Static	3	-67.5	3	3	3	3	3	3	3.0
3-4-3	Dynamic	1	-67.5	2	2	2	2	2	2	2.0
3-4-4	Dynamic	3	-67.5	2	2	2	0	1	1	1.3
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix A – iBiquity/SPARC SHD-T750 Table Radio Test Data

Table A-6 – Change in Enhanced mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	2	1	2	2	2	1.7
3-1-2	Static	3	"OFF"	1	1	1	1	2	2	1.3
3-1-3	Dynamic	1	"OFF"	1	0	1	0	1	0	0.5
3-1-4	Dynamic	3	"OFF"	0	-1	-1	-2	-1	-1	-1.0
3-2-1	Static	1	-106.5	1	1	1	1	1	1	1.0
3-2-2	Static	3	-106.5	1	1	1	1	1	1	1.0
3-2-3	Dynamic	1	-106.5	0	0	0	0	0	-1	-0.2
3-2-4	Dynamic	3	-106.5	-1	-2	-2	-2	-2	-2	-1.8
3-3-1	Static	1	-80.5	2	2	2	2	2	2	2.0
3-3-2	Static	3	-80.5	3	2	2	2	1	2	2.0
3-3-3	Dynamic	1	-80.5	2	1	2	1	1	1	1.3
3-3-4	Dynamic	3	-80.5	0	0	0	-1	-1	0	-0.3
3-4-1	Static	1	-67.5	0	1	1	1	0	1	0.7
3-4-2	Static	3	-67.5	1	1	1	1	1	1	1.0
3-4-3	Dynamic	1	-67.5	0	0	0	0	0	0	0.0
3-4-4	Dynamic	3	-67.5	0	0	0	-2	-1	-1	-0.7
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix B – Delphi Model 28354699 Car Radio Test Data

Table B-1 – Determination of $D_{\min}$ for Core and enhanced modes

Step	Analog Modulation	MDCL Mode	$D_{\min}$ - Core Mode POF (dBm)	AWGN level (dBm /Hz)	$D_{\min}$ - Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-1-1	Off	OFF (standard AM)	-95.6	"OFF"	-86.6	-9	-
2-1-2	Talk, heavily-processed		-94.6	"OFF"	-86.6	-8	0

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table B-2 – Results for Core and Enhanced mode measurements without MDCL

Step	Analog Modulation	MDCL Mode	Core Mode RF level (dBm)	AWGN level at Core Mode POF (dBm /Hz)	Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-2-1	Off	OFF	-89.6	-157.8	-80.6	-9	-
2-2-2	Talk, heavily-processed		-88.6	-157.8	-80.6	-8	0
2-3-1	Off		-61.6	-136.8	-62.6	1	-
2-3-2	Talk, heavily-processed		-61.6	-136.8	-61.6	0	-1
2-4-1	Off		-47.6	-121.8	-47.6	0	-
2-4-2	Talk, heavily-processed		-47.6	-121.8	-47.6	0	0

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table B-3 – Change in Core mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	0	0	0	0	0	-1	-0.2
3-1-2	Static	3	"OFF"	0	0	0	0	0	-1	-0.2
3-1-3	Dynamic	1	"OFF"	0	0	0	-1	-1	-1	-0.5
3-1-4	Dynamic	3	"OFF"	-2	-2	-2	-2	-2	-2	-2.0
3-2-1	Static	1	-109.6	0	1	1	1	1	0	0.7
3-2-2	Static	3	-109.6	-2	-2	-2	-2	-2	-2	-2.0
3-2-3	Dynamic	1	-109.6	-1	-1	0	0	0	0	-0.3
3-2-4	Dynamic	3	-109.6	-2	-2	-2	-2	-3	-3	-2.3
3-3-1	Static	1	-88.6	-1	-2	-2	-1	-2	0	-1.3
3-3-2	Static	3	-88.6	0	-1	0	-1	-1	-1	-0.7
3-3-3	Dynamic	1	-88.6	-2	-2	-1	-2	-1	-1	-1.5
3-3-4	Dynamic	3	-88.6	-3	-4	-3	-4	-4	-4	-3.7
3-4-1	Static	1	-73.6	1	1	0	1	1	1	0.8
3-4-2	Static	3	-73.6	1	2	1	2	1	1	1.3
3-4-3	Dynamic	1	-73.6	0	-1	1	-1	1	0	0.0
3-4-4	Dynamic	3	-73.6	0	-1	0	-2	-2	-1	-1.0

Notes: Tertiary Carriers set to LOW
“OFF” is AWGN at -155.8 dBm/kHz

Appendix B – Delphi Model 28354699 Car Radio Test Data

Table B-4 – Change in Core mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	1	1	1	1	0	0.8
3-1-2	Static	3	"OFF"	1	1	1	1	1	0	0.8
3-1-3	Dynamic	1	"OFF"	1	1	1	0	0	0	0.5
3-1-4	Dynamic	3	"OFF"	-1	-1	-1	-1	-1	-1	-1.0
3-2-1	Static	1	-76.5	1	2	2	2	2	1	1.7
3-2-2	Static	3	-76.5	-1	-1	-1	-1	-1	-1	-1.0
3-2-3	Dynamic	1	-76.5	0	0	1	1	1	1	0.7
3-2-4	Dynamic	3	-76.5	-1	-1	-1	-1	-2	-2	-1.3
3-3-1	Static	1	-50.5	-1	-2	-2	-1	-2	0	-1.3
3-3-2	Static	3	-50.5	0	-1	0	-1	-1	-1	-0.7
3-3-3	Dynamic	1	-50.5	-2	-2	-1	-2	-1	-1	-1.5
3-3-4	Dynamic	3	-50.5	-3	-4	-3	-4	-4	-4	-3.7
3-4-1	Static	1	-37.5	1	1	0	1	1	1	0.8
3-4-2	Static	3	-37.5	1	2	1	2	1	1	1.3
3-4-3	Dynamic	1	-37.5	0	-1	1	-1	1	0	0.0
3-4-4	Dynamic	3	-37.5	0	-1	0	-2	-2	-1	-1.0
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Table B-5 – Change in Enhanced mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	-1	-1	-2	-1	-1	-1	-1.2
3-1-2	Static	3	"OFF"	-1	-1	-1	-1	-1	-1	-1.0
3-1-3	Dynamic	1	"OFF"	-2	-2	-2	-2	-3	-2	-2.2
3-1-4	Dynamic	3	"OFF"	-4	-4	-4	-4	-4	-4	-4.0
3-2-1	Static	1	-76.5	-1	-1	-1	-1	-1	-1	-1.0
3-2-2	Static	3	-76.5	-2	-2	-1	-1	-1	-1	-1.3
3-2-3	Dynamic	1	-76.5	-1	-1	-1	-2	-2	-1	-1.3
3-2-4	Dynamic	3	-76.5	-3	-3	-3	-4	-4	-4	-3.5
3-3-1	Static	1	-50.5	0	0	-1	-1	-1	-1	-0.7
3-3-2	Static	3	-50.5	-1	-1	-1	-1	-1	-1	-1.0
3-3-3	Dynamic	1	-50.5	-1	-1	-1	-1	-2	-2	-1.3
3-3-4	Dynamic	3	-50.5	-3	-3	-3	-3	-3	-3	-3.0
3-4-1	Static	1	-37.5	0	0	-1	0	-1	0	-0.3
3-4-2	Static	3	-37.5	-1	0	0	-1	-1	-1	-0.7
3-4-3	Dynamic	1	-37.5	-2	-1	-1	-1	-2	-2	-1.5
3-4-4	Dynamic	3	-37.5	-4	-3	-4	-4	-3	-3	-3.5
Notes: Tertiary Carriers set to LOW “OFF” is AWGN at -155.8 dBm/kHz										

Appendix B – Delphi Model 28354699 Car Radio Test Data

Table B-6 – Change in Enhanced mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	-1	-1	-2	-1	-1	-1	-1.2
3-1-2	Static	3	"OFF"	-1	-1	-1	-1	-1	-1	-1.0
3-1-3	Dynamic	1	"OFF"	-2	-2	-2	-2	-3	-2	-2.2
3-1-4	Dynamic	3	"OFF"	-4	-4	-4	-4	-4	-4	-4.0
3-2-1	Static	1	-76.5	-1	-1	-1	-1	-1	-1	-1.0
3-2-2	Static	3	-76.5	-2	-2	-1	-1	-1	-1	-1.3
3-2-3	Dynamic	1	-76.5	-1	-1	-1	-2	-2	-1	-1.3
3-2-4	Dynamic	3	-76.5	-3	-3	-3	-4	-4	-4	-3.5
3-3-1	Static	1	-50.5	1	1	0	0	0	0	0.3
3-3-2	Static	3	-50.5	0	0	0	0	0	0	0.0
3-3-3	Dynamic	1	-50.5	0	0	0	0	-1	-1	-0.3
3-3-4	Dynamic	3	-50.5	-2	-2	-2	-2	-2	-2	-2.0
3-4-1	Static	1	-37.5	0	0	-1	0	-1	0	-0.3
3-4-2	Static	3	-37.5	-1	0	0	-1	-1	-1	-0.7
3-4-3	Dynamic	1	-37.5	-2	-1	-1	-1	-2	-2	-1.5
3-4-4	Dynamic	3	-37.5	-4	-3	-4	-4	-3	-3	-3.5
Notes: Tertiary Carriers set to LOW “OFF” is AWGN at -155.8 dBm/kHz										

Appendix C – Sony CEX-GT710HD Car Radio Test Data

Table C-1 – Determination of D_{min} for Core and Enhanced modes

Step	Analog Modulation	MDCL Mode	D_{min} - Core Mode POF (dBm)	AWGN level (dBm /Hz)	D_{min} - Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-1-1	Off	OFF	-101.5	"OFF"	-9	-	"OFF"
2-1-2	Talk, heavily-processed		-101.5	"OFF"	-9	0	"OFF"

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table C-2 – Results for Core and enhanced mode measurements without MDCL

Step	Analog Modulation	MDCL Mode	Core Mode RF level (dBm)	AWGN level at Core Mode POF (dBm /Hz)	Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-2-1	Off	OFF	-95.5	-162.8	-87.5	-8	-
2-2-2	Talk, heavily-processed		-95.5	-162.8	-86.5	-9	-1
2-3-1	Off		-61.5	-126.8	-51.5	-10	-
2-3-2	Talk, heavily-processed		-61.5	-126.8	-50.5	-11	-1
2-4-1	Off		-47.5	-112.8	-39.5	-8	-
2-4-2	Talk, heavily-processed		-47.5	-113.8	-39.5	-8	0

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table C-3 – Change in Core mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	0	-1	0	0	0	0	-0.2
3-1-2	Static	3	"OFF"	-1	-1	0	0	0	0	-0.3
3-1-3	Dynamic	1	"OFF"	-1	-1	-1	-1	-1	-1	-1.0
3-1-4	Dynamic	3	"OFF"	-2	-2	-2	-1	-3	-3	-2.2
3-2-1	Static	1	-106.5	0	0	-1	0	0	-1	-0.3
3-2-2	Static	3	-106.5	0	0	-1	-1	-1	-1	-0.7
3-2-3	Dynamic	1	-106.5	-1	-1	-1	-1	-2	-1	-1.2
3-2-4	Dynamic	3	-106.5	-2	-2	-3	-3	-3	-3	-2.7
3-3-1	Static	1	-80.5	0	0	0	0	0	0	0.0
3-3-2	Static	3	-80.5	-1	0	0	0	0	0	-0.2
3-3-3	Dynamic	1	-80.5	0	-1	0	0	-1	-1	-0.5
3-3-4	Dynamic	3	-80.5	-2	-2	-3	-3	-3	-3	-2.7
3-4-1	Static	1	-67.5	1	1	1	1	1	1	1.0
3-4-2	Static	3	-67.5	1	1	1	0	0	0	0.5
3-4-3	Dynamic	1	-67.5	0	0	0	0	0	0	0.0
3-4-4	Dynamic	3	-67.5	-1	-1	-1	-1	-2	-2	-1.3
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix C – Sony CEX-GT710HD Car Radio Test Data

Table C-4 – Change in Core mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	0	-1	0	0	0	0	-0.2
3-1-2	Static	3	"OFF"	-1	-1	0	0	0	0	-0.3
3-1-3	Dynamic	1	"OFF"	-1	-1	-1	-1	-1	-1	-1.0
3-1-4	Dynamic	3	"OFF"	-2	-2	-2	-1	-3	-3	-2.2
3-2-1	Static	1	-106.5	0	0	-1	0	0	-1	-0.3
3-2-2	Static	3	-106.5	0	0	-1	-1	-1	-1	-0.7
3-2-3	Dynamic	1	-106.5	-1	-1	-1	-1	-2	-1	-1.2
3-2-4	Dynamic	3	-106.5	-2	-2	-3	-3	-3	-3	-2.7
3-3-1	Static	1	-80.5	0	0	0	0	0	0	0.0
3-3-2	Static	3	-80.5	-1	0	0	0	0	0	-0.2
3-3-3	Dynamic	1	-80.5	0	-1	0	0	-1	-1	-0.5
3-3-4	Dynamic	3	-80.5	-2	-2	-3	-3	-3	-3	-2.7
3-4-1	Static	1	-67.5	1	1	1	1	1	1	1.0
3-4-2	Static	3	-67.5	1	1	1	0	0	0	0.5
3-4-3	Dynamic	1	-67.5	0	0	0	0	0	0	0.0
3-4-4	Dynamic	3	-67.5	-1	-1	-1	-1	-2	-2	-1.3
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix D – Volkswagen RCD510 Car Radio Test Data

Table D-1 – Determination of $D_{\min}$ for Core and Enhanced modes

Step	Analog Modulation	MDCL Mode	$D_{\min}$ - Core Mode POF (dBm)	AWGN level (dBm /Hz)	$D_{\min}$ - Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-1-1	Off	OFF	-94.5	"OFF"	-84.5	-10	-
2-1-2	Talk, heavily-processed		-93.5	"OFF"	-83.5	-10	-1

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table D-2 – Results for Core and Enhanced mode measurements without MDCL

Step	Analog Modulation	MDCL Mode	Core Mode RF level (dBm)	AWGN level at Core Mode POF (dBm /Hz)	Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-2-1	Off	OFF	-88.5	-156.8	-78.5	-10	-
2-2-2	Talk, heavily-processed		-87.5	-155.8	-77.5	-10	-1
2-3-1	Off		-62.5	-127.8	-52.5	-10	-
2-3-2	Talk, heavily-processed		-62.5	-127.8	-51.5	-11	-1
2-4-1	Off		-48.5	-114.8	-38.5	-10	
2-4-2	Talk, heavily-processed		-48.5	-113.8	-38.5	-10	0

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table D-3 – Change in Core mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	-1	0	-1	-1	0	-1	-0.7
3-1-2	Static	3	"OFF"	-1	-1	0	-1	0	0	-0.5
3-1-3	Dynamic	1	"OFF"	-1	-2	-2	-3	-2	-2	-2.0
3-1-4	Dynamic	3	"OFF"	-3	-3	-4	-4	-4	-4	-3.7
3-2-1	Static	1	-107.5	-1	0	-1	-1	-1	-1	-0.8
3-2-2	Static	3	-107.5	0	-1	0	-1	-1	0	-0.5
3-2-3	Dynamic	1	-107.5	-1	-2	-1	-1	-1	-1	-1.2
3-2-4	Dynamic	3	-107.5	-2	-2	-2	-3	-3	-3	-2.5
3-3-1	Static	1	-79.5	0	0	0	0	0	0	0.0
3-3-2	Static	3	-79.5	-1	0	0	0	0	0	-0.2
3-3-3	Dynamic	1	-79.5	-1	-1	-1	-1	-1	-1	-1.0
3-3-4	Dynamic	3	-79.5	-2	-3	-3	-4	-2	-3	-2.8
3-4-1	Static	1	-65.5	0	0	0	0	-1	0	-0.2
3-4-2	Static	3	-65.5	0	-1	-1	-1	-1	-1	-0.8
3-4-3	Dynamic	1	-65.5	0	-1	-1	-2	-1	-2	-1.2
3-4-4	Dynamic	3	-65.5	-1	-3	-2	-3	-4	-3	-2.7
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix D – Volkswagen RCD510 Car Radio Test Data

Table D-4 – Change in Core mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	0	1	0	0	1	0	0.3
3-1-2	Static	3	"OFF"	0	0	1	0	1	1	0.5
3-1-3	Dynamic	1	"OFF"	0	-1	-1	-2	-1	-1	-1.0
3-1-4	Dynamic	3	"OFF"	-2	-2	-3	-3	-3	-3	-2.7
3-2-1	Static	1	-107.5	0	1	0	0	0	0	0.2
3-2-2	Static	3	-107.5	1	0	1	0	0	1	0.5
3-2-3	Dynamic	1	-107.5	0	-1	0	0	0	0	-0.2
3-2-4	Dynamic	3	-107.5	-1	-1	-1	-2	-2	-2	-1.5
3-3-1	Static	1	-79.5	0	0	0	0	0	0	0.0
3-3-2	Static	3	-79.5	-1	0	0	0	0	0	-0.2
3-3-3	Dynamic	1	-79.5	-1	-1	-1	-1	-1	-1	-1.0
3-3-4	Dynamic	3	-79.5	-2	-3	-3	-4	-2	-3	-2.8
3-4-1	Static	1	-65.5	0	0	0	0	-1	0	-0.2
3-4-2	Static	3	-65.5	0	-1	-1	-1	-1	-1	-0.8
3-4-3	Dynamic	1	-65.5	0	-1	-1	-2	-1	-2	-1.2
3-4-4	Dynamic	3	-65.5	-1	-3	-2	-3	-4	-3	-2.7
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix E –JVC KW-NT50HDT Car Radio Test Data

Table E-1 – Determination of $D_{\min}$ for Core and Enhanced modes

Step	Analog Modulation	MDCL Mode	$D_{\min}$ - Core Mode POF (dBm)	AWGN level (dBm /Hz)	$D_{\min}$ - Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-1-1	Off	OFF	-73.6	"OFF"	-84.6	-11	-
2-1-2	Talk, heavily-processed		-72.6	"OFF"	-83.6	-11	-1

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table E-2 – Results for Core and Enhanced mode measurements without MDCL

Step	Analog Modulation	MDCL Mode	Core Mode RF level (dBm)	AWGN level at Core Mode POF (dBm /Hz)	Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-2-1	Off	OFF	-67.6	-143.8	-78.6	-11	-
2-2-2	Talk, heavily-processed		-66.6	-142.8	-77.6	-11	-1
2-3-1	Off		-52.6	-126.8	-61.6	-9	-
2-3-2	Talk, heavily-processed		-51.6	-126.8	-61.6	-10	-1
2-4-1	Off		-39.6	-113.8	-47.6	-8	-
2-4-2	Talk, heavily-processed		-39.6	-113.8	-47.6	-8	0

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table E-3 – Change in Core mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/Hz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	0	-1	0	0	0	0	-0.2
3-1-2	Static	3	"OFF"	0	1	0	0	0	1	0.3
3-1-3	Dynamic	1	"OFF"	0	0	0	-2	0	-1	-0.5
3-1-4	Dynamic	3	"OFF"	-2	-2	-2	-3	-3	-2	-2.3
3-2-1	Static	1	-94.6	-2	-2	-2	-2	-2	-3	-2.2
3-2-2	Static	3	-94.6	-3	-3	-3	-3	-4	-4	-3.3
3-2-3	Dynamic	1	-94.6	-4	-3	-4	-4	-4	-4	-3.8
3-2-4	Dynamic	3	-94.6	-5	-7	-5	-6	-7	-6	-6.0
3-3-1	Static	1	-78.6	0	0	0	-1	0	0	-0.2
3-3-2	Static	3	-78.6	-1	0	0	0	-1	-2	-0.7
3-3-3	Dynamic	1	-78.6	-1	-2	-1	-2	-1	-2	-1.5
3-3-4	Dynamic	3	-78.6	-2	-3	-3	-3	-3	-4	-3.0
3-4-1	Static	1	-65.6	1	0	0	0	0	0	0.2
3-4-2	Static	3	-65.6	0	1	0	0	0	0	0.2
3-4-3	Dynamic	1	-65.6	0	0	0	-1	0	-1	-0.3
3-4-4	Dynamic	3	-65.6	-1	-3	-2	-3	-2	-2	-2.2
Notes: Tertiary Carriers set to LOW “OFF” is AWGN at -155.8 dBm/kHz										

Appendix E –JVC KW-NT50HDT Car Radio Test Data

Table E-4 – Change in Core mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	0	1	1	1	1	0.8
3-1-2	Static	3	"OFF"	1	2	1	1	1	2	1.3
3-1-3	Dynamic	1	"OFF"	1	1	1	-1	1	0	0.5
3-1-4	Dynamic	3	"OFF"	-1	-1	-1	-2	-2	-1	-1.3
3-2-1	Static	1	-94.6	-1	-1	-1	-1	-1	-2	-1.2
3-2-2	Static	3	-94.6	-2	-2	-2	-2	-3	-3	-2.3
3-2-3	Dynamic	1	-94.6	-3	-2	-3	-3	-3	-3	-2.8
3-2-4	Dynamic	3	-94.6	-4	-6	-4	-5	-6	-5	-5.0
3-3-1	Static	1	-78.6	0	0	0	-1	0	0	-0.2
3-3-2	Static	3	-78.6	-1	0	0	0	-1	-2	-0.7
3-3-3	Dynamic	1	-78.6	-1	-2	-1	-2	-1	-2	-1.5
3-3-4	Dynamic	3	-78.6	-2	-3	-3	-3	-3	-4	-3.0
3-4-1	Static	1	-65.6	1	0	0	0	0	0	0.2
3-4-2	Static	3	-65.6	0	1	0	0	0	0	0.2
3-4-3	Dynamic	1	-65.6	0	0	0	-1	0	-1	-0.3
3-4-4	Dynamic	3	-65.6	-1	-3	-2	-3	-2	-2	-2.2
Notes: Tertiary Carriers set to LOW “OFF” is AWGN at -155.8 dBm/kHz										

Table E-5 – Change in Enhanced mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	-9	-9	-9	-9	-9	-9	-9.0
3-1-2	Static	3	"OFF"	-8	-9	-9	-9	-9	-9	-8.8
3-1-3	Dynamic	1	"OFF"	-12	-13	-13	-13	-13	-13	-12.8
3-1-4	Dynamic	3	"OFF"	-14	-14	-15	-16	-17	-17	-15.5
3-2-1	Static	1	-94.6	-4	-4	-4	-4	-5	-4	-4.2
3-2-2	Static	3	-94.6	-4	-4	-4	-4	-5	-4	-4.2
3-2-3	Dynamic	1	-94.6	-6	-7	-7	-7	-7	-7	-6.8
3-2-4	Dynamic	3	-94.6	-8	-8	-7	-9	-9	-9	-8.3
3-3-1	Static	1	-78.6	-1	-2	-1	-2	-2	-1	-1.5
3-3-2	Static	3	-78.6	-1	-2	-2	-1	-2	-2	-1.7
3-3-3	Dynamic	1	-78.6	-2	-2	-2	-2	-2	-3	-2.2
3-3-4	Dynamic	3	-78.6	-3	-3	-4	-4	-4	-4	-3.7
3-4-1	Static	1	-65.6	0	0	0	0	0	0	0.0
3-4-2	Static	3	-65.6	0	0	0	-1	0	-1	-0.3
3-4-3	Dynamic	1	-65.6	-1	-1	-1	-2	-1	-1	-1.2
3-4-4	Dynamic	3	-65.6	-2	-3	-3	-3	-3	-3	-2.8
Notes: Tertiary Carriers set to LOW “OFF” is AWGN at -155.8 dBm/kHz										

Appendix E –JVC KW-NT50HDT Car Radio Test Data

Table E-6 – Change in Enhanced mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	-8	-8	-8	-8	-8	-8	-8.0
3-1-2	Static	3	"OFF"	-7	-8	-8	-8	-8	-8	-7.8
3-1-3	Dynamic	1	"OFF"	-11	-12	-12	-12	-12	-12	-11.8
3-1-4	Dynamic	3	"OFF"	-13	-13	-14	-15	-16	-16	-14.5
3-2-1	Static	1	-94.6	-3	-3	-3	-3	-4	-3	-3.2
3-2-2	Static	3	-94.6	-3	-3	-3	-3	-4	-3	-3.2
3-2-3	Dynamic	1	-94.6	-5	-6	-6	-6	-6	-6	-5.8
3-2-4	Dynamic	3	-94.6	-7	-7	-6	-8	-8	-8	-7.3
3-3-1	Static	1	-78.6	0	-1	0	-1	-1	0	-0.5
3-3-2	Static	3	-78.6	0	-1	-1	0	-1	-1	-0.7
3-3-3	Dynamic	1	-78.6	-1	-1	-1	-1	-1	-2	-1.2
3-3-4	Dynamic	3	-78.6	-2	-2	-3	-3	-3	-3	-2.7
3-4-1	Static	1	-65.6	0	0	0	0	0	0	0.0
3-4-2	Static	3	-65.6	0	0	0	-1	0	-1	-0.3
3-4-3	Dynamic	1	-65.6	-1	-1	-1	-2	-1	-1	-1.2
3-4-4	Dynamic	3	-65.6	-2	-3	-3	-3	-3	-3	-2.8
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Appendix F – Kenwood KDC-BT621HD Car Radio Test Data

Table F-1 – Determination of $D_{\min}$ for Core and Enhanced modes

Step	Analog Modulation	MDCL Mode	$D_{\min}$ - Core Mode POF (dBm)	AWGN level (dBm /Hz)	$D_{\min}$ - Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-1-1	Off	OFF	-99.6	"OFF"	-89.6	-10	-
2-1-2	Talk, heavily-processed		-99.6	"OFF"	-88.6	-11	-1

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table F-2 – Results for Core and Enhanced mode measurements without MDCL

Step	Analog Modulation	MDCL Mode	Core Mode RF level (dBm)	AWGN level at Core Mode POF (dBm /Hz)	Enhanced Mode POF (dBm)	Enhanced – Core Mode (delta dB)	Enhanced Mode Mod - No-Mod (delta dB)
2-2-1	Off	OFF	-93.6	-84.6	-9	-	-
2-2-2	Talk, heavily-processed		-93.6	-84.6	-9	0	-1
2-3-1	Off		-61.6	-51.6	-10	-	-
2-3-2	Talk, heavily-processed		-61.6	-51.6	-10	0	0
2-4-1	Off		-47.6	-37.6	-10	-	-
2-4-2	Talk, heavily-processed		-47.6	-37.6	-10	0	0

Note: "OFF" is AWGN at -155.8 dBm/kHz

Table F-3 – Change in Core mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	0	0	-1	0	0	0	-0.2
3-1-2	Static	3	"OFF"	0	-1	0	0	0	0	-0.2
3-1-3	Dynamic	1	"OFF"	-1	-2	-2	-1	-1	-2	-1.5
3-1-4	Dynamic	3	"OFF"	-2	-3	-3	-3	-3	-3	-2.8
3-2-1	Static	1	-112.6	0	-1	0	0	0	0	-0.2
3-2-2	Static	3	-112.6	1	0	-1	0	-1	-1	-0.3
3-2-3	Dynamic	1	-112.6	-1	-1	-1	-1	-1	-1	-1.0
3-2-4	Dynamic	3	-112.6	-2	-3	-3	-3	-2	-4	-2.8
3-3-1	Static	1	-78.6	0	-1	0	-1	0	-1	-0.5
3-3-2	Static	3	-78.6	-1	0	0	-1	0	-1	-0.5
3-3-3	Dynamic	1	-78.6	-1	-1	-1	-1	-1	-2	-1.2
3-3-4	Dynamic	3	-78.6	-3	-3	-3	-4	-3	-4	-3.3
3-4-1	Static	1	-65.6	1	1	1	1	0	1	0.8
3-4-2	Static	3	-65.6	0	-1	0	0	1	0	0.0
3-4-3	Dynamic	1	-65.6	0	0	0	-1	0	0	-0.2
3-4-4	Dynamic	3	-65.6	-1	-2	-2	-2	-2	-2	-1.8
Notes: Tertiary Carriers set to LOW “OFF” is AWGN at -155.8 dBm/kHz										

Appendix F – Kenwood KDC-BT621HD Car Radio Test Data

Table F-4 – Change in Core mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	0	0	-1	0	0	0	-0.2
3-1-2	Static	3	"OFF"	0	-1	0	0	0	0	-0.2
3-1-3	Dynamic	1	"OFF"	-1	-2	-2	-1	-1	-2	-1.5
3-1-4	Dynamic	3	"OFF"	-2	-3	-3	-3	-3	-3	-2.8
3-2-1	Static	1	-112.6	0	-1	0	0	0	0	-0.2
3-2-2	Static	3	-112.6	1	0	-1	0	-1	-1	-0.3
3-2-3	Dynamic	1	-112.6	-1	-1	-1	-1	-1	-1	-1.0
3-2-4	Dynamic	3	-112.6	-2	-3	-3	-3	-2	-4	-2.8
3-3-1	Static	1	-78.6	0	-1	0	-1	0	-1	-0.5
3-3-2	Static	3	-78.6	-1	0	0	-1	0	-1	-0.5
3-3-3	Dynamic	1	-78.6	-1	-1	-1	-1	-1	-2	-1.2
3-3-4	Dynamic	3	-78.6	-3	-3	-3	-4	-3	-4	-3.3
3-4-1	Static	1	-65.6	1	1	1	1	0	1	0.8
3-4-2	Static	3	-65.6	0	-1	0	0	1	0	0.0
3-4-3	Dynamic	1	-65.6	0	0	0	-1	0	0	-0.2
3-4-4	Dynamic	3	-65.6	-1	-2	-2	-2	-2	-2	-1.8
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Table F-5 – Change in Enhanced mode POF with MDCL vs. no MDCL with no analog modulation (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	1	0	0	0	0	0	0.2
3-1-2	Static	3	"OFF"	0	1	0	0	1	1	0.5
3-1-3	Dynamic	1	"OFF"	0	0	0	0	-1	0	-0.2
3-1-4	Dynamic	3	"OFF"	-2	-3	-2	-2	-2	-2	-2.2
3-2-1	Static	1	-112.6	-1	0	-1	0	-1	0	-0.5
3-2-2	Static	3	-112.6	0	-1	0	0	0	0	-0.2
3-2-3	Dynamic	1	-112.6	-1	-1	-1	-1	-1	-1	-1.0
3-2-4	Dynamic	3	-112.6	-3	-3	-3	-4	-3	-3	-3.2
3-3-1	Static	1	-78.6	0	0	-1	0	0	0	-0.2
3-3-2	Static	3	-78.6	0	0	0	0	0	0	0.0
3-3-3	Dynamic	1	-78.6	-1	0	-1	0	-1	0	-0.5
3-3-4	Dynamic	3	-78.6	-2	-2	-3	-2	-3	-3	-2.5
3-4-1	Static	1	-65.6	2	2	1	1	1	1	1.3
3-4-2	Static	3	-65.6	2	2	2	2	2	2	2.0
3-4-3	Dynamic	1	-65.6	0	1	0	1	0	1	0.5
3-4-4	Dynamic	3	-65.6	-1	-1	-1	-1	-1	-1	-1.0
Notes: Tertiary Carriers set to LOW “OFF” is AWGN at -155.8 dBm/kHz										

Appendix F – Kenwood KDC-BT621HD Car Radio Test Data

Table F-6 – Change in Enhanced mode POF with MDCL vs. no MDCL with talk-heavy processing (dB) – negative numbers represent a degradation in POF

				CHANGE IN POF (dB)						
Step	MDCL mode	AMC compression (dB)	AWGN level (dBm/kHz)	Audio type and processing						Mean
				Light		Medium		Heavy		
				Talk	Music	Talk	Music	Talk	Music	
3-1-1	Static	1	"OFF"	2	1	1	1	1	1	1.2
3-1-2	Static	3	"OFF"	1	2	1	1	2	2	1.5
3-1-3	Dynamic	1	"OFF"	1	1	1	1	0	1	0.8
3-1-4	Dynamic	3	"OFF"	-1	-2	-1	-1	-1	-1	-1.2
3-2-1	Static	1	-76.5	-1	0	-1	0	-1	0	-0.5
3-2-2	Static	3	-76.5	0	-1	0	0	0	0	-0.2
3-2-3	Dynamic	1	-76.5	-1	-1	-1	-1	-1	-1	-1.0
3-2-4	Dynamic	3	-76.5	-3	-3	-3	-4	-3	-3	-3.2
3-3-1	Static	1	-50.5	0	0	-1	0	0	0	-0.2
3-3-2	Static	3	-50.5	0	0	0	0	0	0	0.0
3-3-3	Dynamic	1	-50.5	-1	0	-1	0	-1	0	-0.5
3-3-4	Dynamic	3	-50.5	-2	-2	-3	-2	-3	-3	-2.5
3-4-1	Static	1	-37.5	2	2	1	1	1	1	1.3
3-4-2	Static	3	-37.5	2	2	2	2	2	2	2.0
3-4-3	Dynamic	1	-37.5	0	1	0	1	0	1	0.5
3-4-4	Dynamic	3	-37.5	-1	-1	-1	-1	-1	-1	-1.0
Notes: Tertiary Carriers set to LOW "OFF" is AWGN at -155.8 dBm/kHz										

Table F-7 – Audio tests from LF jack, relative to 1 kHz @ 30% modulation

RF attn. (dB)	RF level (dBm)	Audio out (VRMS)	THD (%)	WQPSNR (dB)
40	-47.6	0.296	0.09	60
54	-61.6	0.295	0.17	48
86	-93.6	0.303	4.2	20
92	-99.6	0.306	6.3	17
Notes: THD measurements at two lowest signals are increased because of noise RF levels derived from Core mode POF values in Table and Table				

Plan for Compatibility Testing of AM MDCL with Hybrid AM IBOC Waveforms on Standard Consumer and OEM Receivers

This test program will provide NAB and CEA (co-sponsors of the National Radio Systems Committee) with objective laboratory test data to assess the compatibility of Modulation Dependent Carrier Level (MDCL) systems on the performance of standard IBOC receivers. The test plan herein will evaluate reception of hybrid AM IBOC over a wide range of RF levels when MDCL is applied in each of two different modes and at various analog modulation levels.

Test System

The MDCL tests will be performed on standard consumer and original equipment (OEM) car AM IBOC receivers, to measure the effect on their digital reception. Table G-1 lists the receivers used for testing.

Table G-1 – IBOC AM-capable receivers used for testing

Category	Brand	Model No.	Radio Description and chipset (if known)	Year (approx.)
Automotive OEM	Delphi	28354699	FM/AM/HD (GM #22922854)	2014
	Volkswagen	RCD510	In-dash double-DIN	2013
Automotive aftermarket	Sony	CEX-GT710HD	FM-/AM/HD 1-DIN, ST Micro chipset	2013
	Kenwood	KTC-BT762HD	FM-/AM/HD in-dash 1-DIN, SiLab-4763 (tuner), SiLab-4613 (HD Radio)	2015
	JVC	KW-NT50HDT	FM-/AM/HD in-dash 1-DIN	2013
Table/indoor	iBiquity/SPARC	SHD-T750	FM/AM/HD, Helio chipset	2013

Figure G-1 shows the primary interconnections between the instrumentation and the receiver under test. A dashed line indicates a temporary connection to record processed digital audio samples for use by Nautel in its analysis of MDCL power efficiency.

Receiver Signal Input

The automotive receivers provide unbalanced, shielded connectors for antenna input. These inputs will be used for direct connection to the test IBOC RF generator. Recent co-channel interference tests of receiver performance of all-digital AM radio, conducted by NAB Labs, used RF desired signal input levels of -48 dBm, -62 dBm and -76 dBm, representing “strong”, “moderate” and “weak” signal conditions, respectively. The values are not associated with any particular field strength contours, but were recommended by the NRSC’s MDCL Working Group for these tests. However, the group will be modified by including a minimum IBOC digital sideband reception threshold and making the “weak” signal level 6 dB greater than the threshold. RF levels will be referenced to a nominal 50 ohm load, in place of the receiver.

In addition the receivers will be measured for analog audio signal-to-noise ratio at each RF signal level, with and without AWGN noise, at the hybrid digital “point of failure” (POF). This will help characterize the receiver’s analog performance over a wide range of received signal conditions.

The iBiquity/SPARC table radio uses an external loop antenna for AM. The loop is connected through an antenna connector on the back of the radio. A signal feed recommended by iBiquity, using a series 11 μ H choke to simulate the antenna, as shown in Figure G-1, will be used.

Appendix G – Test Plan

Test Procedure, Reference Values

Receiver sensitivity for IBOC digital reception of normal (non-MDCL) signals will be established by detecting the POF of digital reception using the tests shown in Table G-2.¹ After connecting a receiver to the RF signal and tuning the receiver, the following steps are used to establish the baseline hybrid IBOC POF at minimum signal (Step 2-1) and as a function of channel CNR² at three desired RF levels (Steps 2-2 through 2-4).

Table G-2 – Reference measurements of hybrid IBOC point of failure without MDCL

Step	Analog Modulation	MDCL mode	AM RF level Adjustment	AWGN Adjustment	Measurement Result	Audio SNR Measurement (modulation on)
2-1	Off and with heavily-processed talk	OFF	Reduce until POF	OFF	RF level, Dmin (MDCL off)	Yes
2-2		OFF	Set to 6 dB above Dmin in Step 1	ON, raise until POF	AWGN for weak signal (6 dB above Dmin)	Yes
2-3		OFF	Set to -62 dBm	ON, raise until POF	AWGN for medium signal	Yes
2-4		OFF	Set to -48 dBm	ON, raise until POF	AWGN for strong signal	Yes

Measurement of the audio signal-to-noise ratio (SNR) of the analog receiver output will be collected with the AWGN on, but may be collected in each step for two AWGN levels if the final (digital POF) values differ between the modulation-off case and heavily-processed talk modulation. Measurements will use weighted quasi-peak metering (ITU-R BS.468-4). The audio SNR will be referenced to 1 kHz at 30 percent modulation.

Test Procedure, MDCL Conditions

Table G-3 lists the test conditions that are to be tested with each receiver, for a series of MDCL modes. With each MDCL mode and modulation condition, the AM RF level will be set sufficiently above the values discovered in Table G-2 with heavily-processed talk modulation to ensure solid digital reception. The AM RF level is then decreased until the POF with MDCL is determined. The intention is to determine the change in desired RF level, if any (and the relative change in associated AWGN, if any) for POF when various MDCL modes are introduced compared to the cases with no MDCL.

¹ Consumer receivers do not offer a measure of uncorrected bit error ratio, thus, it is necessary to rely on audio decoded by IBOC circuitry to determine POF. In lieu of this, the IBOC signal will carry a continuous audio tone which will be monitored for silence, which indicates digital reception failure.

² The carrier-to-noise ratio at which digital reception failure occurs will be determined by measuring signal power of the AM carrier, relative to the noise in a 20 kHz bandwidth using the Channel Power feature of a digital spectrum analyzer, absent the AM carrier and digital sidebands.

Appendix G – Test Plan

Table G-3 – Conditions for MDCL compatibility test

Step	Analog Modulation	MDCL mode	AM RF level Adjustment	AWGN Adjustment	Measurement Result
3-1	As specified in Table 7 (6 AM audio processing conditions for each MDCL case)	ON	Reduce until POF	OFF	RF level, Dmin (MDCL on)
3-2		ON	Initially, set above RF value in Step 2-1, decrease until POF	ON, set to same power in Step 2-2 (w/modulation)	RF level, dBm
3-3		ON	Initially, set above -62 dBm, decrease until POF	ON, set to same power in Step 2-3 (w/modulation)	RF level, dBm
3-4		ON	Initially, set above -48 dBm, decrease until POF	ON, set to same power in Step 2-4 (w/modulation)	RF level, dBm

Table G-4 illustrates the proposed matrix for the two MDCL modes (Static and Dynamic) and two compression conditions (1 dB and 3 dB). All of the tests in Table G-3 will be conducted for each of the numbered cells in Table G-4. Both static and dynamic MDCL modes are tested with AMC at levels of 1 dB and 3 dB. A Nautel-supplied exciter will be utilized for generation of both modes.

Table G-4 – Matrix of MDCL RF and Audio Processing (Nautel exciter Audio Settings shown in italics)

MDCL Mode	Audio Processing Level	Light		Medium		Heavy	
		Talk	Music	Talk	Music	Talk	Music
Static: <i>IBOC in mode:</i> <i>Constant Level</i>	MDCL Algorithm: <i>AM Mode >AMC</i>						
	<i>Compression: 1.0 dB</i>	<i>4-1</i>	<i>4-2</i>	<i>4-3</i>	<i>4-4</i>	<i>4-5</i>	<i>4-6</i>
	<i>Compression: 3.0 dB</i>	<i>4-7</i>	<i>4-8</i>	<i>4-9</i>	<i>4-10</i>	<i>4-11</i>	<i>4-12</i>
Dynamic: <i>IBOC in mode:</i> <i>IBOC Tracks</i> <i>Carrier</i>	MDCL Algorithm: <i>AM Mode >AMC</i>						
	<i>Compression: 100 dB</i>	<i>4-13</i>	<i>4-14</i>	<i>4-15</i>	<i>4-16</i>	<i>4-17</i>	<i>4-18</i>
	<i>Compression: 3.0 dB</i>	<i>4-19</i>	<i>4-20</i>	<i>4-21</i>	<i>4-22</i>	<i>4-23</i>	<i>4-24</i>

The Signal Settings and Audio Settings for the Nautel exciter, which are common to all tests, are shown in Table G-5.

Appendix G – Test Plan

Table G-5 – Signal and Audio Settings of Nautel exciter (Nautel terminology)

Signal Settings	
	Upper Primary LVL > 0.00 dB
	Lower Primary LVL > 0.00 dB
	Digital Carriers > ON (except OFF for AM-only tests in section 2 of the Test Plan)
	Enhanced Carriers > LOW (experiment with OFF and HIGH for comparison)
	AM Service Mode > MA-1 (Hybrid)
	Mag DC Offset > 0.00 V
	Mag/Phase Delay > 109.540 us
Audio Settings	
	Input Source > I/Q & AES; IBOC
	Low Pass Filter > LPF Disable
	Pre-emphasis Filter > OFF
	AM Mode > AMC
	DCC Compression > See table from test plan, Table G-4
	IBOC in DCC Mode > See table from test plan, Table G-4

The potential for impact to IBOC digital sideband reception may vary with different analog AM modulation conditions, such as the type of program modulation and amount of audio processing (dynamic compression and limiting). The test will be performed with talk and music material using light, medium and heavy audio processing.

There are 96 conditions (4 step conditions from Table G-3 times 24 algorithms and modes from Table G-4) tested for each receiver, in addition to the 8 reference measurements per receiver described earlier, for a total of 500 measurements. The results of the change in desired signal levels will be charted for each receiver and included in the final report. Due to variability in the performance of receivers and the measurement process, it is expected that differences of less than 1 dB within individual receiver data are not significant. When results are averaged across all receivers, differences of more than 0.5 dB may be considered significant.

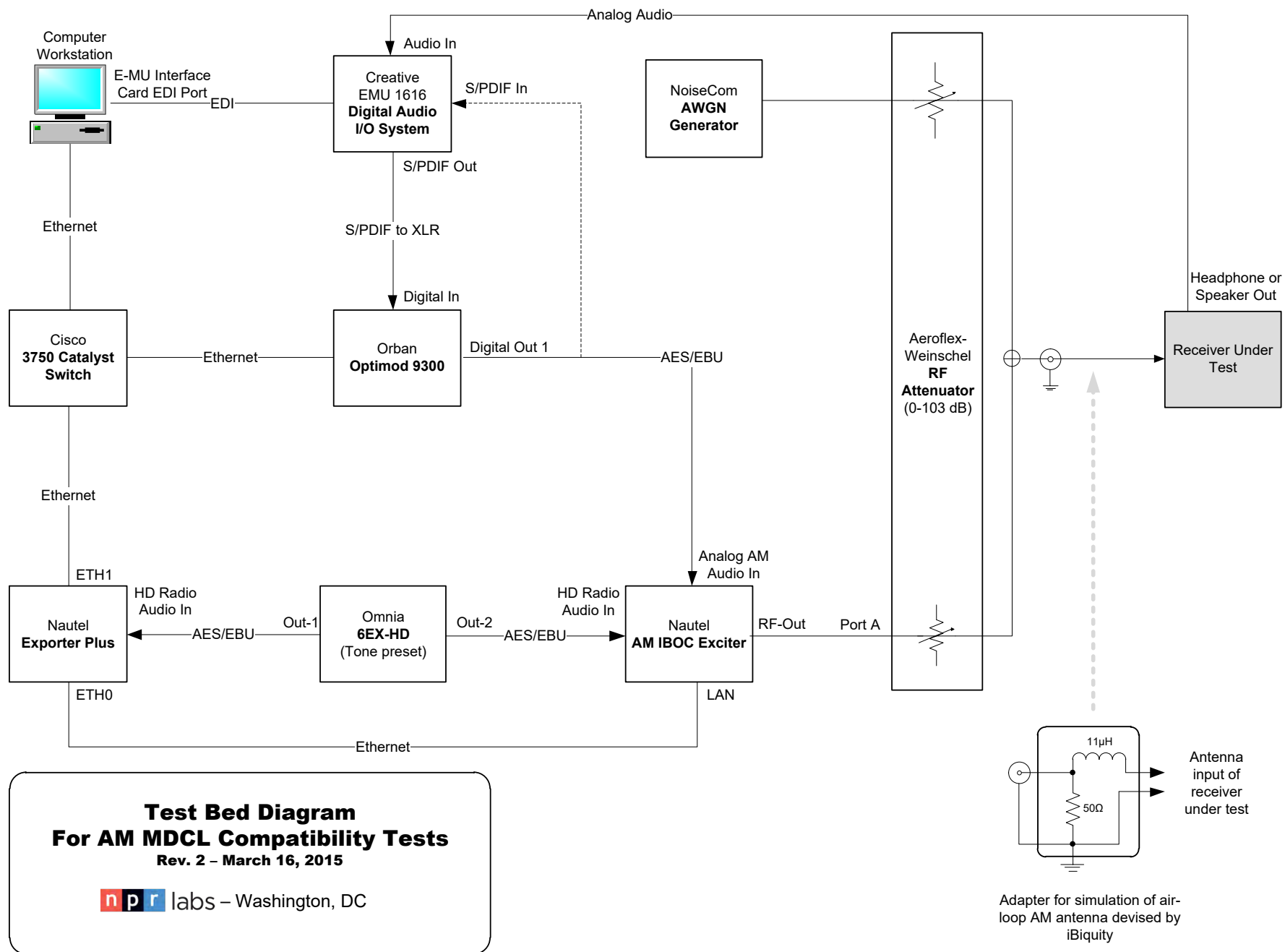


Figure G-1 – Diagram of test equipment connections
G-5

NRSC-G101-A

NRSC Document Improvement Proposal

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