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Submission to an Ad-Hoc vendor working group for a DOCSIS ECR
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1. Introduction

This note is submitted in support of a change in DOCSIS specifications for spurious performance. It shows that the impact of a proposed change is negligible and that the advantages far outweigh the perceived disadvantages of adopting such a change.

2. DOCSIS' specifications' exclusion for discrete spurs is intended only for Non-Aggregating Spurious components.

In its Table 6-15, the DOCSIS RF Interface Specifications [1] ("DOCSIS RFI") currently specifies the permitted noise and spurious levels within a single channel for channels other than the three otherwise specified adjacent channel bands. The noise specification is given by:

Other channels (47 MHz to 1,000 MHz)	< -12dBmV in each 6 MHz channel, excluding up to three discrete spurs. The total power in the spurs must be < -60 dBc when each is measured with 10kHz bandwidth.

The –12 dBmV absolute noise and spurious level corresponds to a –73 dBc requirement when one considers the single channel maximum RF power requirement of 61 dBmV. For reasons explained in [2], it is argued that the absolute level specification should be replaced by the relative dBc specification. Regardless of that premise, it becomes clear that the –60 dBc exclusion for discrete spurs is an intended relaxation by as much as 13 dB compared to the requirements for other noise components. The rationale for this relaxation was not, and *cannot* be, due to the discrete nature (as opposed to the noise-like nature) of the excluded components. If anything, discrete components interfering with analog channels are significantly more objectionable subjectively than wide bandwidth noise components having the same relative power [3]. Indeed, protection of analog channels from interfering discrete carrier components are generally known to require much higher margins (by more than 10 dB) than that from random noise [4]. Moreover, the effect of discrete spectral components on the installed base of digital demodulators is inconsistent and in many cases just as damaging as that from random noise having the same relative power. It is thus argued that the –60 dBc exclusion was introduced to the DOCSIS RFI due to a recognition that implementation imperatives necessitated such relaxation under an unstated understanding that there would be very little or no superposition or spectral aggregation of such components emanating from multiple QAM transmission devices. Although the current language in the DOCSIS RFI does not expressly qualify the exclusion of these discrete spurious components to those that do not spectrally aggregate over a given 6 MHz channel from different QAM devices tuned to distinct channels, the specification must be construed to mean that, because otherwise it would presumably be possible to aggregate from 100 such combined devices spurs that can reach cumulative spurious levels of –40 dBc in a given 6 MHz channel. Clearly, such result cannot be tolerated in any head-end system. We therefore conclude that ***the DOCSIS RFI already provides for spectrally non-aggregating spurious components to reach a combined level of –60 dBc in a 6 MHz channel***. It is argued that virtually ***no further*** loss of other channel protection would be incurred if harmonics are among such excluded spectrally non-aggregating spurious components.

3. Including harmonics in DOCSIS' spectrally non-aggregating spurious specifications would result in virtually no loss of other channels' protection.

Because combined QAM sources are tuned to distinct channels, their harmonics do not coincide in frequency and therefore the spurious harmonic components do not spectrally aggregate. It is possible, however, that a second harmonic of a first QAM source falls on the same channel as that of the third harmonic of a second QAM source. For all practical purposes, the harmonic levels are such that we need concern ourselves only with the second and third harmonics. The accumulation of two such components from QAM channels and their noise degradation effect on analog channels was treated by a prior submission to this working group [5], wherein it is shown that for cable system delivering an end-of-line Carrier-to-Noise Ratio ("CNR") of 50 dB, the CNR degradation difference between limiting harmonics specifications to a –73 dBc and limiting it up to –60 dBc is only 0.14 dB. A more likely scenario, however, is that the victim channel is a digital channel situated at the top of the band. The comparison of the effects on a digital channel is presented in Table 1 and further explained below.

Case	Item	Modulator in-channel Equivalent Noise	Broadband Noise (Other Channels)	First adjacent channel	Second adjacent channel	Non-Aggregating Harmonics	Tx Noise Aggregation Factor	Other zones' co-channel interference	Distribution Plant Contribution	Subscriber Terminal C/N
ECR Proposal	Relative level/Ch (dBc)	-41.8	-73.0	-62	-65	-60		-70		
	# of degraders	1	50 sources	2 sources	2 sources	2 sources		15 ports	many	
	Composite	-41.8	-56.0	-59.0	-62.0	-57.0	-41.40	-58.2	-44.0	-39.44 dBc
Current DOCSIS RFI	Relative level/Ch (dBc)	-41.8	-73.0	-62	-65	-73		-70		
	# of degraders	1	50 sources	2 sources	2 sources	2 sources		15 ports	many	
	Composite	-41.8	-56.0	-59.0	-62.0	-70.0	-41.52	-58.2	-44.0	-39.52 dBc

Difference	0.07 dB

Modulator, Single Channel

Zone's Combined Channels

Combined Effect from all Zones (Head-End Output)

Plant degradations up to subscriber terminal (excluding Head-End)

Total at Subscriber terminal

Table 1. Comparison of cumulative noise budgets for 50 digital channels having existing DOCSIS RF specifications and the proposed DOCSIS ECR. Note that the only entry in variance is in the Non-Aggregating Harmonics category (cell with color background), yielding an insignificant subscriber terminal difference of only 0.07 dB.

For a given digital channel with other neighboring digital channels having frequencies above and below it, we follow a structure of noise degradation accumulation as described in [6], arriving at a Noise Aggregation Factor which is the overall combined effect at the head-end combining network. Here, we include the In-Channel equivalent MER. Because the Nyquist bandwidth is nearly the channel width, within a tenth of a dB, the modulator's MER is equal to its output In-Channel effective CNR in 6 MHz. The –41.8 dBc entry is comprised of the –48 dBc allowance for In-Channel noise and the DOCSIS phase noise limit equivalent of –43 dBc as described in [2]. Being on the conservative side however, we do not include the downstream plant CSO and CTB but rather, we derive a total equivalent CNR comparison showing the difference in margins that are left for such uncertain degradations that may be significantly different from one subscriber installation to another. Finally, we assume that the plant noise contribution for the analog channels is resulting in 50 dB CNR, which corresponds to 44 dB for a 256 QAM channel inserted at –6 dB relative to analog peak sync level. As can be seen from the right-most column of Table 1, relaxing the second and third harmonic specification limit from –73 dBc to –60 dBc results in an insignificant 0.07 dB loss of noise margin.

We therefore conclude that broadening the scope of the DOCSIS exclusion for spectrally non-aggregating spurious components from discrete spurs only to include harmonics, would result in virtually no loss of protection and would simplify compliance testing substantially. The alternative specification language for multiple channels we propose is as follows:

Other channels (47 MHz to 1,000 MHz):	Less than $-73+10\cdot\log_{10}(N)$ dBc in each 6 MHz channel referenced to a single channel, where N is the number of QAM carriers in the group, excluding spectrally non-aggregating (carrier frequency related) spurs and/or second or third harmonics. The total power in the spurs and harmonics in a 6 MHz channel must be < -60 dBc referenced to a single channel.

It might be argued that the performance implications of adopting the above specification language instead of the existing specification is that a protection margin loss of 0.14 dB would be incurred and that, however small the potential degradation is, cable operators must have a compelling reason to accept any such change. In other words, there must be tangible and real advantages to the *cable operator and its customers* that clearly outweigh the disadvantages for adopting such change. We submit that a clear and convincing case can be made for such tangible advantages. The advantages are related to lower power consumption, increased density permitting deployment in smaller hub space, improved reliability and lower manufacturing and testing costs, as further addressed below.

4. Operator Advantages.

The implications for QAM hardware implementation with the current DOCSIS RFI specification implying that harmonic components must be lower than –73 dBc are profound. A design of such devices that complies with this limit over a frequency tuning range spanning a decade, necessarily requires the use of much higher power RF devices, increases size and increases the reliability challenge. It also requires lengthier and more expensive testing and compliance verification. The advantages for setting harmonic spurious specifications to –60 dBc are addressed in the following sections.

4.1 Power Consumption Savings.

If a designer wishes to improve on the harmonic specification of an existing RF output amplifier circuit as shown in Figure 1(a), he might consider building the variable band-pass filter at the very output of the RF stage so as to reject excessive harmonic distortion components generated by the push-pull RF output amplifier as shown in Figure 1(b). The problem with this approach is that (a) it requires higher dynamic range filter switching or tuning devices that can sustain higher power levels without causing harmonic distortion of their own. More importantly, however, is the fact that the configuration of Figure 1(b) results in extremely poor output return loss on channels other than that tuned to by the filter. Such a reflective output structure can cause a significant Narrowcast isolation degradations with resultant co-channel noise degradation that far exceed the fraction of a dB we may be trying to address here. These co-channel network combining isolation issues have been elaborated on in [6]. An alternative path for harmonic distortion improvements would therefore be that of brute force increase in the linearity (Output Intercept Point) of the RF output amplifier as shown in Figure 1(c).

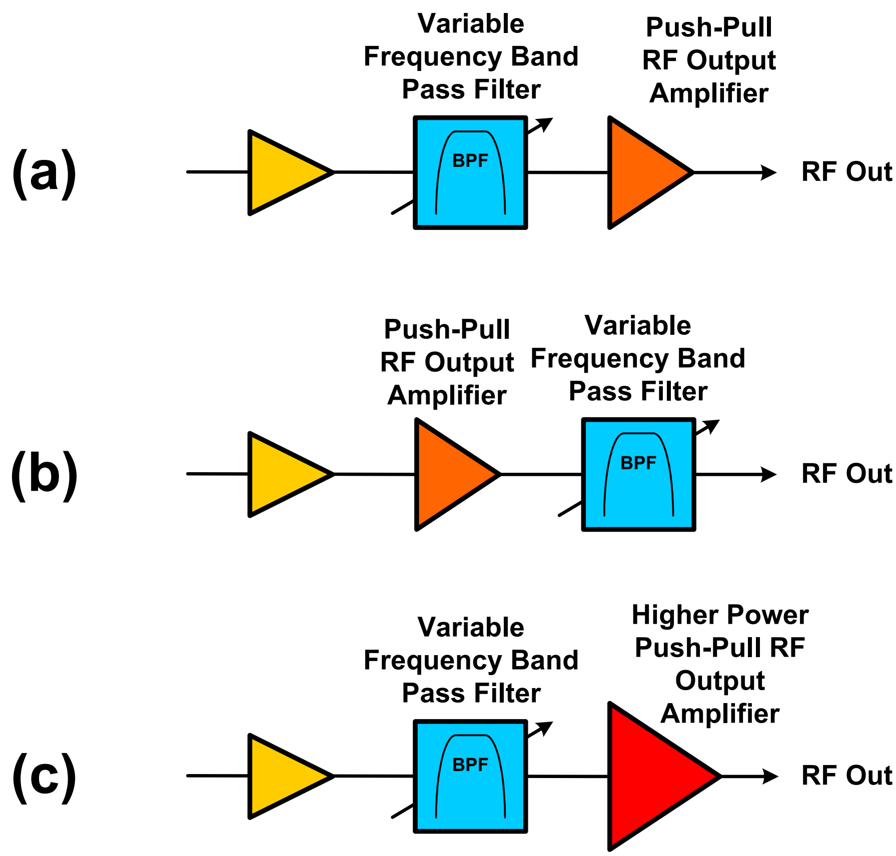

Figure 1. Possible RF output structure configurations for QAM RF modulators or upconverters. Improvements in harmonic rejection specifications can be made by placing a filter at the very output as in (**b**), with adverse impact on output return loss specifications, or by increasing the linearity of the output stage with higher power amplifier as in (**c**), resulting in substantial increase in DC power requirements.

In that configuration, one can ostensibly achieve both good broadband return loss and improved harmonic distortion performance. It is thus important to realize that modern frequency agile QAM RF modulators and upconverters do not employ frequency selective filters at their output due to the latter having significant RF power losses and because such filters, by their very nature, frustrate the maintenance of a reasonable off-channel output return loss. Therefore, unaided by further harmonic filtering, the output amplifier stage must sustain the distortion specification by its sheer linearity performance. For any amplifier with a given RF output power level, the relative second and third harmonic distortion performance is proportional to the amplifier's second order output intercept point ("IP2") and third order output intercept point ("IP3") respectively. A lower relative distortion level requires higher intercept point. Figure 2 shows both second and third order intercept points for various push-pull amplifier devices as a function of their respective DC power consumption. In each case, the intercept point for one arm of the push-pull device is shown so as to eliminate the variability and dependence on the superposition and canceling effects of the balance transformers.

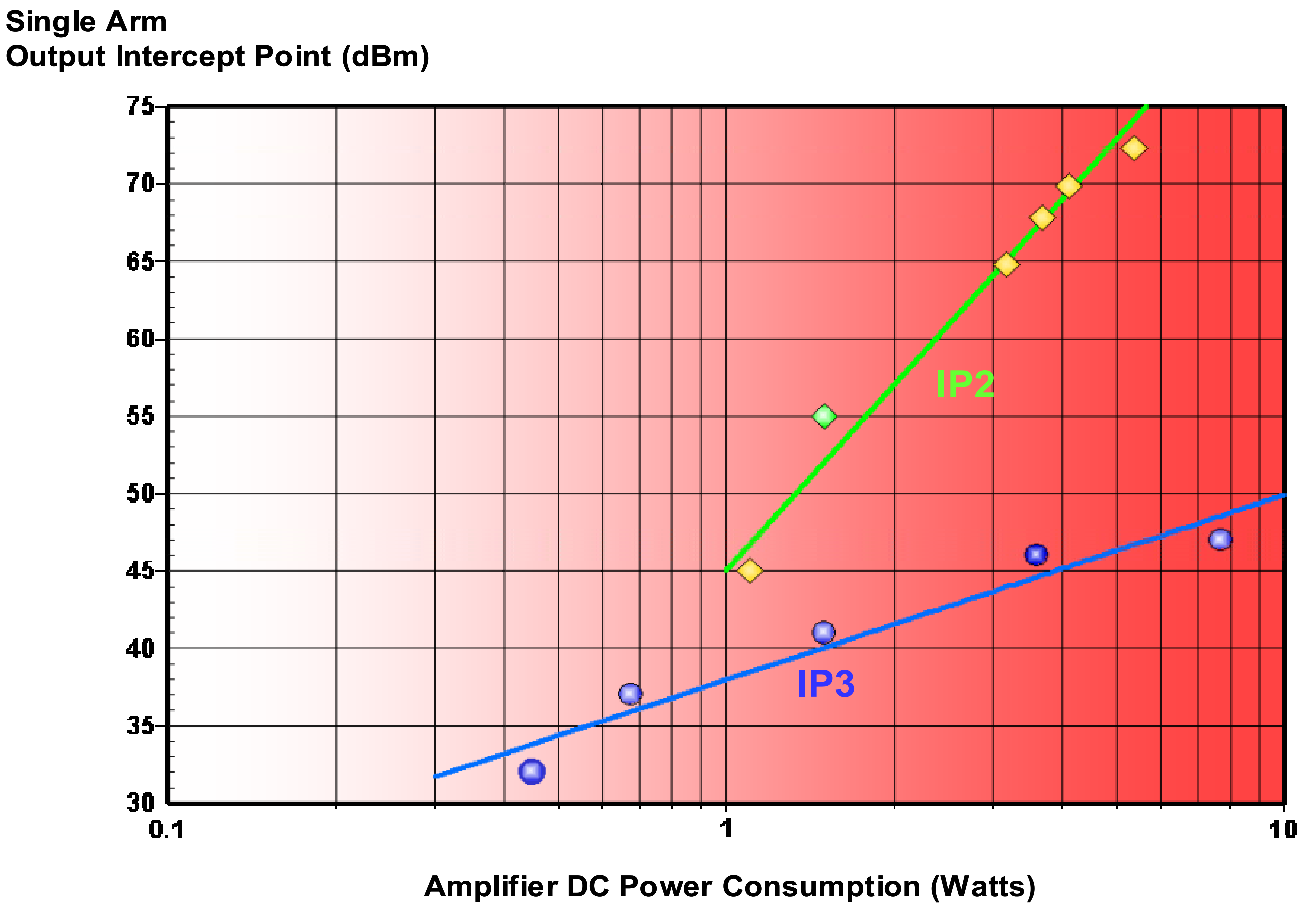

Figure 2 Distortion performance of various semiconductor RF push-pull amplifier devices as a function of their DC power consumption. Both second order intercept points (IP2) and third order intercept points (IP3) are provided for a single arm of each push-pull amplifier device.

As can be seen in Figure 2, when roughly observed across the range, every relaxation of 12 dB in IP2 requirement permits an output amplifier stage design that consumes half of the DC power. From the definition of IP2, such a relaxation means a resultant relaxation of a second harmonic specification by 12 dB. Similarly, as depicted in that Figure, a relaxation of 6 dB in IP3 requirement permits a design of an output amplifier stage that consumes roughly a third of the DC power. From the definition of IP3, such a relaxation means a relaxation of a third harmonic specification by 12 dB. ***Thus, the proposed harmonic specification relaxation can result in power savings of output power amplifiers by at least a factor of two***. For the maximum DOCSIS output power to be sustained with a –73 dBc harmonic levels, a DC power close to 5 Watts would be required and the total potential power savings can be up to 3 Watts per channel. Because the output power amplifier is a dominant power hog, there are significant collateral savings associated with more than halving the DC power consumption of the output amplifier. These are:

- Derating significantly the DC supply switcher and regulator power requirements.
- Simplification of heat transfer and cooling facilities (and related reduction of forced air fan motor power consumption).
- Reduction of physical size and improve overall density.
- Improved reliability (MTBF).

Any reasonable examination of the above factors alone should be persuasive enough for adopting our proposed change described in Section 3. However, there are more reasons:

4.2 Savings Related to Compliance Verification, Manufacturing and Test.

DS Intf	4	
Frequency	93	MHz
Modulation	QAM64	
Power	61	dBmV

Measurement	Freq (MHz)	Power (dBmV)	Spur1 (dBmV)	Spur2 (dBmV)	Spur3 (dBmV)	SpurSum (dBmV)	BndPwr Minus SpurSum (dBmV)	BndPwr minus SpurSum (dBc)	BndPwr Limit (dBc or (dBmV)	P/F	SpurSum (dBc)	SpurSum Limit (dBc)	P/F
Reference Pwr	**93.000**	**61.04**											
-750kHz Skirt	88.875	-4.86					-4.86	-65.9	-58	-P-			
+750kHzSkirt	97.125	-6.19					-6.19	-67.23	-58	-P-			
-1st Adj Chan	86.625	-2.37	-23.01	-24.02	-24.48	-19.02	-2.46	-63.51	-62	-P-	-80.06	-60	-P-
-2nd Adj Chan	81.000	-9.49	-31.39	-31.53	-31.70	-26.77	-9.57	-70.61	-65	-P-	-87.81	-60	-P-
+1st Adj Chan	99.375	-2.71	-24.92	-25.66	-25.82	-20.68	-2.78	-63.83	-62	-P-	-81.72	-60	-P-
+2nd Adj Chan	105.000	-7.10	-24.86	-24.88	-29.76	-21.20	-7.27	-68.31	-65	-P-	-82.25	-60	-P-
50 MHz Chan	50.00	-20.54	-39.93	-44.62	-44.73	-37.70	-20.62		-12	-P-	-98.74	-60	-P-
51 MHz Chan	51.00	-20.55	-40.53	-40.79	-44.03	-36.75	-20.66		-12	-P-	-97.79	-60	-P-
57 MHz Chan	57.00	-20.70	-38.94	-41.80	-44.81	-36.45	-20.82		-12	-P-	-97.49	-60	-P-
63 MHz Chan	63.00	-20.48	-34.53	-38.11	-44.57	-32.66	-20.75		-12	-P-	-93.70	-60	-P-
69 MHz Chan	69.00	-20.15	-36.35	-43.81	-44.36	-35.08	-20.30		-12	-P-	-96.13	-60	-P-
75 MHz Chan	75.00	-17.07	-39.84	-39.85	-39.91	-35.09	-17.14		-12	-P-	-96.13	-60	-P-
111 MHz Chan	111.00	-14.42	-36.63	-36.73	-36.77	-31.94	-14.50		-12	-P-	-92.98	-60	-P-
117 MHz Chan	117.00	-20.53	-42.03	-43.27	-44.53	-38.38	-20.60		-12	-P-	-99.43	-60	-P-
123 MHz Chan	123.00	-21.87	-43.61	-45.86	-45.93	-40.22	-21.93		-12	-P-	-101.26	-60	-P-
129 MHz Chan	129.00	-22.80	-45.42	-45.86	-46.73	-41.20	-22.87		-12	-P-	-102.24	-60	-P-
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993 MHz Chan	993.00	-25.30	-49.10	-49.59	-49.72	-44.69	-25.35		-12	-P-	-100.34	-60	-P-
997 MHz Chan	997.00	-25.28	-49.50	-49.70	-49.78	-44.89	-25.33		-12	-P-	-100.54	-60	-P-

Figure 3. An example of Downstream Spurious test report of Agilent's E1371A DOCSIS Test System. Note that for every transmitted channel tested (93 MHz in this example), all other channels from 50 MHz to 1 GHz are each searched for the three strongest discrete spurs using 10 kHz resolution bandwidth.

The current DOCSIS RFI spur exclusion for three discrete terms requires measuring power levels in ***600 frequency bins that are 10 kHz wide on every channel***. Figure 3 shows a compliance test result of such measurement for a transmitted channel at 93 MHz. This type of test must be repeated for every transmitted channel under test, for at least two power levels (typically at 61 dBmV and 50 dBmV) and for both 64 QAM and 256 QAM. Currently such tests take tens of hours to complete and are by far the longest among the DOCSIS RFI test suite. Our proposed change described in Section 3, would not require narrow resolution bandwidth, which slows down the measurement, because it calls for measuring the total integrated spurious power over 6 MHz regardless of the nature of the noise component. It is estimated that tests that take days to complete now would be completed in only a few hours.

Ensuring a –73 dBc specification for harmonic distortion over a frequency range covering more than three octaves requires careful design and testing to tight specification limits. Upon an harmonic distortion specification relaxation to –60 dBc, vendors would have an option to use the margin in two ways. The first is to design a lower power device with all its attendant advantages as discussed above. The second is to use some of the margin to maintain a larger dB distance from the mean distortion level to the specification limit, thereby assuring virtual certainty of compliance for every unit produced leading to the elimination or reduction of recurring manufacturing tests designed to test harmonic distortion compliance. Of course, a combination of the two strategies is most beneficial. It should be emphasized that reducing the number of channels on which each manufactured unit must be tested for harmonic distortion can result in significant manufacturing cost savings. Manufacturing testing time may be cut by as much as 30% and first-pass yield improvements could be realized. These are tangible advantages that would undoubtedly translate to shorter supply times and lower costs for the cable operator.

5. Conclusion.

Substantial cost and operational benefits exist for making the proposed specification change for modulated harmonic distortion. The increase in the number of downstream channels and the increase in density sought by operators for their future deployments, strongly suggests that these benefits will become even more significant in the near future.

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