

Presented before the  
**National Translator Association**  
on May 17, 2008

Where are the White Spaces in the Broadcast  
TV Spectrum?

By  
Charles W. Rhodes  
Retired Chief Scientist  
Advanced Television Test Center Inc.  
Consultant to the TV Industry  
Feature Technical Writer,  
“TV TECHNOLOGY” Magazine  
Fellow IEEE & SMPTE

## **Where are the White Spaces in the Broadcast TV Spectrum?”**

*The FCC is committed to allow sharing of the remaining (Post-Transition) Broadcast spectrum. A Consortium seeks to deploy millions of unlicensed “wireless interface links” to computers and other data storage, processing, and display units by utilizing “vacant channels”, the so-called “White Spaces” within the TV broadcast spectrum. Translator operators will be affected by such sharing so you should understand how signals from such unlicensed devices will affect DTV reception of your DTV signals. So where are these “White Spaces”?*

### **Perhaps they are the Low VHF Channels, 2 – 6?**

Several years ago, Byron told me that a senator had suggested re-deploying the Low VHF portion of the broadcast TV spectrum for use by unlicensed devices. That was an excellent concept. If you have limited RF power to radiate, everyone knows that you should use the lowest possible frequency. But many do not know why. It is because the power intercepted by an antenna is proportional to the capture area of the antenna. At 50 MHz, a resonant antenna has a really large capture area so it captures a lot of power from the wave. This is the main reason that TV stations in the UHF band need to radiate so much Effective Radiated Power (ERP) compared to low VHF stations. But alas, the proponents of sharing of broadcast spectrum are intent on sharing all of it; furthermore, they do not covet our Low VHF spectrum. Now that is really curious. Their lobbyists have told Congressmen and Senators and the FCC Commissioners that they need this spectrum to provide free over-the-air interconnection to the Internet for constituents living in sparsely settled areas where the costs of long distance telephone charges are simply too much of a burden to bear. The Consortium has lobbied that interference to DTV reception by unlicensed devices is a Myth spread by broadcasters. They said they could and would protect broadcasting. The use of the Low VHF Band got nowhere because there was so much support generated by the lobbyists for this worthy public goal that restricting it to just a portion of the TV spectrum was rejected.

For the record, I think this was a great idea. There are 40 allotments of Low VHF channels in the final plan adopted by the FCC in August, 2007. That is a mere 8 allotments per channel nation-wide. This cannot be considered efficient spectrum management.

Well, maybe over time, that senator's idea will be recognized. Folks needing to have a wireless path extending over many miles, not just a few feet, will find that the low VHF band is well suited to their needs but this requires a large antenna. They have the space for a large antenna. Many already have such an antenna and it won't be needed for TV reception after February, 2009. A comparison of radiated power at Low VHF and in the UHF band shows how much more power is needed at UHF because of the small UHF antennas. That power ratio is something like 23 : 1. Unfortunately some are asking the FCC to authorize sharing of TV channels 21-51 only, forsaking any chance for long distance wireless interconnections possible with lower frequencies.

### **Perhaps they are the “vacant channels” next to a local broadcast allotment?**

The Consortium has claimed that they need to use these vacant Adjacent channels to realize the scale of operation needed to reduce costs to assure that the service is widely used. I don't doubt this. But the technical problems in making them work are formidable.

There are lots of high power DTV transmitters now in the UHF band, and there will be more as a result of the next FCC Window opening August, 2008 in which more pleadings for maximization will be filed. Meanwhile the number of maximized DTV facilities of 500 kW and above breaks down as:

500 – 599 kW ERP	77
600 – 699 kW ERP	41
700 - 799kW ERP	48
800 – 899 kW ERP	38
900 – 999 kW ERP	41
<b>1000 kW ERP</b>	<b><u>331</u></b>
<b>Total</b>	<b>576</b>

Unlicensed devices may ray radiate up to 4 watts. This should be contrasted with the above ERP in the UHF band for broadcaster's signals.

## **Sideband Splatter Radiated by DTV Transmitters.**

The sideband splatter which a DTV station can legally radiate in each of the channels adjacent to its allocated channel is about 46.5 dB below the radiated power in its allocated channel. This is up to 22 watts average power or 88 watts peak power in each adjacent channel. Interference relates to peak power, coverage to average power. This 88 watts of peak power can be considered as noise in adjacent channels radiated from atop a broadcast tower.

The FCC has indicated that it will allow two classes of unlicensed devices, portable and fixed to operate on vacant channels in the TV broadcast spectrum. Portable devices, being battery powered may be limited to 100 mW Effective Isotropic Peak Power EIRP. Fixed devices may be allowed up to 4 watts EIRP. The problem is that the broadcaster may be putting up to 88 watts into a vacant channel which an unlicensed device is trying to use with his 4 watt or less signal.

**Question: “How can a 4-watt ‘minnow’ swim upstream against an 88-watt current (the broadcaster’s sideband splatter in the same channel)? Well, I don’t know either.**

Perhaps it is more important to ask how far a 100 milliwatt ‘minnow’ from a portable unlicensed device can swim towards its nearby receiver which is receiving noise in that channel radiated by a broadcaster at 88 watts peak from his broadcast tower?

But a much more subtle question is; what kind of frequency agile tuners will these unlicensed devices have that can tolerate the 1 megawatt broadcaster signal on a first adjacent channel to that the receiver is tuned to?

Why am I asking this? Because it is well known that Adjacent Channel Interference between DTV signals is due to the fact that consumer DTV receivers overload at a received signal power of about – 25 dBm and when they are overloaded, they generate 3<sup>rd</sup> order Intermodulation products which fall in the first adjacent channels where the minnows are trying to swim upstream. So, if radiated sideband splatter doesn’t get these minnows, the 3<sup>rd</sup> order IM products generated in the receivers will! But I have just mixed up the receivers of unlicensed devices with DTV receivers haven’t I? Yes, and here is why I did it.

Where do you think the manufacturers of unlicensed devices are going to obtain the frequency agile tuners for broadcast TV channels (21- 51) needed for their unlicensed devices? Answer: from the firms already making them for DTV receivers. We already know that these tuners overload at about - 25 dBm in DTV receivers, so they will do the same thing when applied to unlicensed devices. I could be wrong, perhaps tuner manufacturers will offer more robust tuners to both markets, but frankly tuners for such markets are extremely cost sensitive. So my conclusion is that “white spaces” are not going to be found in vacant channels adjacent to channels in use by broadcasters.

The Consortium has requested permission to conduct field tests to determine whether their “minnows” can swim against the broadcaster’s current in the same channel. The FCC has just granted a Special Temporary Authority (STA) to conduct such tests in Washington, DC. Perhaps these field tests will prove definitive.

### **Perhaps white spaces will be found to be practical if polarization protection is used?**

#### **First off, what is polarization protection?**

In Europe, some TV signals are radiated with vertical wave polarization. This practice began in 1936 in England. They had their dipole antennas in a vertical plane, which vertically polarized their radiated waves. In the U.S., we decided to use horizontal wave polarization for TV because of automobile ignition noise in the 40-90 MHz TV band in 1939. Our dipoles have always been in horizontal planes and that practice has long endured.

**Theoretically a vertically polarized wave cannot be received by a horizontally polarized dipole, and a horizontally polarized wave cannot be picked up by a vertically polarized dipole. This is the theory behind the concept of polarization protection.**

**Three questions immediately arise:**

1. Does the theory work? It works to the extent that the polarized wave does not suffer de-polarization as it propagates. It does suffer de-polarization in passing through trees. I have measured this personally at several locations (Maryland and Oregon). I found that when I rotated the antenna around its axis so it went from being vertically polarized to being horizontally polarized and back again; there was no plane of the antenna in which the received signal actually nulled, or even decreased significantly where there are trees in the path or nearby. It works in deserts, at sea, and it should work on mountain tops above the tree line.
2. Wouldn't the FCC have to change its Rules? NO!

First, the FCC Rules for DTV are unchanged from the rules for Analog TV concerning polarization. The FCC has never required the use of horizontal wave polarization for DTV stations. I would add that FM broadcasters long ago found that circular polarization (a combination of vertically and horizontally polarized waves of equal power) was useful for FM reception in automobiles. With the present level of interest by broadcasters who already have the right to radiate circular, elliptical, horizontal, or vertical wave polarization of their radiated TV signals, they will not give up on this without a fight..

**Broadcasters have the right to radiate vertically polarized waves.**

They will in all probability increase such practice for mobile DTV reception in automobiles.

3. How could the FCC require portable unlicensed devices to radiate only vertically polarized waves? I have no idea.

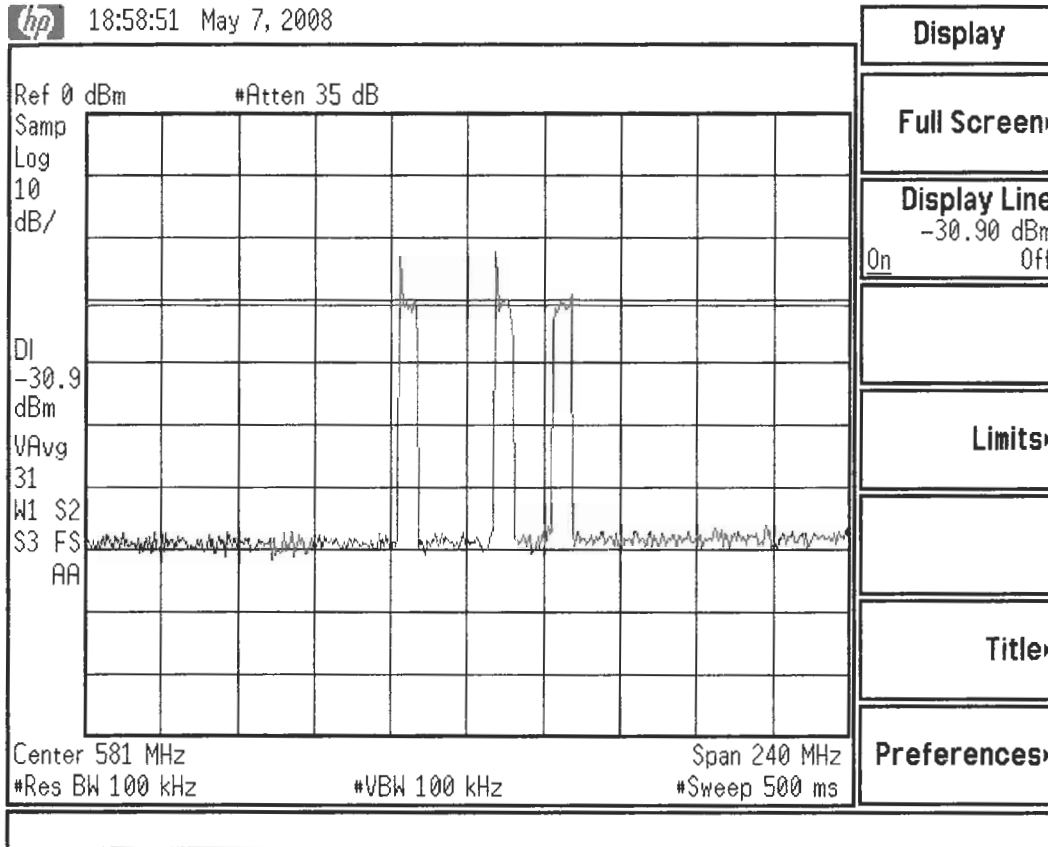
**I conclude that we will not find "white spaces" through polarization protection.**

**Perhaps unlicensed devices can operate on vacant channels offset by more than one channel from a local broadcast channel? (Non-Adjacent Channels).**

First, I want to show you Figure 1, a spectrum plot of three DTV signals offset by more than one channel. There are DTV signals on channels 29, 34 and 37. In this scheme vacant channels such as 23, 27, 31, 32, and 44 are examples of vacant channels which might be used by unlicensed devices. Look very carefully at the noise level in the vacant

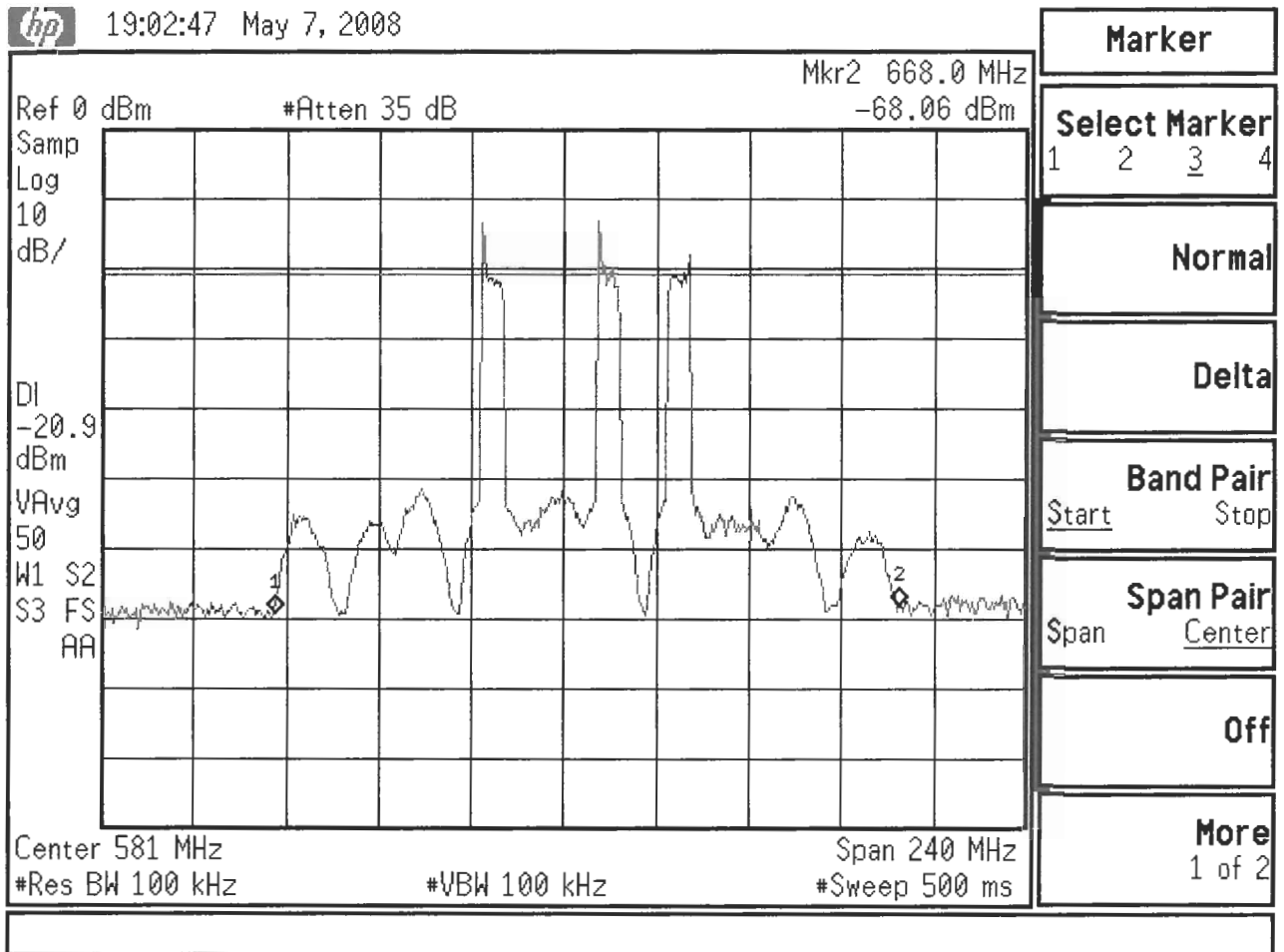
channels of this spectrum plot. The noise level is very low. At and below this received signal level, the tuner is linear; any 3<sup>rd</sup> order distortion products being generated are below the noise floor harming no one.

Figure 1: Undistorted DTV Signals on Channels 29, 34, and 37.



Now look at Figure 2, where these signals are at 10 dBm higher than in Figure 1. Note the noise in the vacant channels 23, 27, 31, 32, and & 44 has dramatically increased. This is the noise that the unlicensed devices must overcome for their signals to be receivable. We have already shown that even if the unlicensed devices have a vertically polarized antenna, it will pick up DTV signals.

**Figure 2: Same DTV Signals increased 10 dB in power to overload the Amplifier Under Test 3rd Order IM Products appear on nearby channels.**



The noise floor in these channels is now much higher because the tuner is overloaded generating 3<sup>rd</sup> order distortion products. Even so, all three of these signals can still be received and decoded. Reception is OK despite tuner overloading. In fact the owner has no idea that his set is generating distortion products. Where are these distortion products? They appear in the vacant channels as shown in Figure 2. What cannot be decoded are signals weaker than these three DTV signals.

In Figure 2, the three DTV signals are above the noise floor by more than the ATSC signal's threshold Signal-to-Noise Power Ratio (15.2 dB). The noise floor in the "vacant" channels in Figure 2 has increased by 30 dB due to 3<sup>rd</sup> order distortion products being generated in the overloaded tuner by the combined power of these signals. The noise

floor in these “vacant” channels is given in Figure 2. Whatever the threshold Signal-to-Noise Power ratio is for the signals transmitted by these unlicensed devices their signals

must be received above the noise floor in the tuners of the unlicensed receivers which is made much higher by its 3<sup>rd</sup> order distortion products.

I should digress slightly here to show how you can figure out where such distortion products will appear in your community. Let’s start with the triplet of broadcast signals shown in Figure 2. Lets call these A (ch. 29), B (ch. 34) and C (ch. 37).

There are two kinds of 3<sup>rd</sup> order distortion products.

The first is 3<sup>rd</sup> order Intermodulation (IM<sub>3</sub>):

2\*A – B & 2\*B – A chs. 24 & 39

2\*B – C & 2\*C – B chs. 31 & 40

2\*C – A & 2\*A – C chs. 45 & 21

These are shown in BLUE in Figure 2.

Third Order Intermodulation takes place when the second harmonic of one signal beats with the fundamental frequency of the other signal.

Note that there are always 6 new channels due to IM<sub>3</sub>.

The second is triple beat cross-modulation:

A +/- ( C – B) chs. 26 & 32

B +/- ( C – A) chs. 26 & 42

C +/- ( B – A) chs. 32 & 42

These are shown in RED in Figure 2.

This 3<sup>rd</sup> order distortion product can only be generated when there are three (or more) strong signals present.

Note that there are only 3 new channels due to triple-beat cross modulation, but there are two such distortion products for each so they appear 3 dB higher in power in these three channels.

Now, lets order these distortion products: 21, 24, 26, **31**, 32, 39, 40, 42, and 45,  
26 32 42

Now lets add the 3 signal channels (**bold**): 21, **24**, 26, **29**, 31, 32, **34**, **37**, 39, 40, 42, 45

Each of these signals when combined in the received signal, generates 3<sup>rd</sup> order distortion products which are always 3 channels wide. These are the “Bee-Hives” you see in Figure 2 and didn’t see in Figure 1, the undistorted signals at the receiver’s input. The channel numbers above are the center channels of these “Bee-Hives”. The side-channels of these “Bee-Hives” are 3<sup>rd</sup> order distortion products which are 6 dB lower in power that



**Tables A-9 and A-10 of the above report show the threshold U levels for D = - 53 dBm and for D = - 68 dBm. The surprising thing in these tables is that interference from signals offset by more than one channel from the desired signal and which is now known to be due to 3<sup>rd</sup> order non-linearity of the receiver front-ends in DTV receivers is significant.**

For example, at D = - 68 dBm, (Table A-9) and D = - 53 dBm (Table A-10) shows the threshold U power for the median DTV receiver:

	D = - 68 dBm	D = - 53 dBm
N+1	- 28.3 dBm	N+1 - 13.6 dBm
N+2	- 25.7 dBm	N+2 - 10.9 dBm
N+3	- 13.3 dBm	N+3 - 3.2 dBm
N+4	- 11.4 dBm	N+4 - 2.9 dBm
N+5	- 9.6 dBm	N+5 - 4.0 dBm
N+6	- 4.9 dBm	N+6 - 2.2 dBm
<b>N+7</b>	<b>-14.8 dBm</b>	<b>N+7 - 14.3 dBm an unanticipated sensitivity</b>
N+8	- 3.0 dBm	N+8 > - 1.6 dBm
N+9	- 2.2 dBm	N+9 > - 1.7 dBm
N+10	- 3.0 dBm	N+10 > - 1.8 dBm

The unanticipated sensitivity to an undesired signal on N+7 has not been investigated but is confirmed by studies in Canada reported earlier.

Pairs of Undesired DTV signals of the form N+K & N+2K were also tested by the FCC and results reported in Tables A-9 & A-10...

N+1, N+2	- 31.5 dBm	N+1, N+2	- 17.6 dBm	<b>predicted increase in sensitivity</b>
N+2, N+4	- 30.0 dBm	N+2, N+4	- 14.8 dBm	“ “ “ “
N+3, N+6	- 24.5 dBm	N+3, N+6	- 18.8 dBm	“ “ “ “
N+4, N+8	- 21.2 dBm	N+4, N+8	- 17.2 dBm	“ “ “ “
N+5, N+10	- 19.7 dBm	N+5, N+10	- 14.2 dBm	“ “ “ “

The predicted increase in sensitivity of certain pairs of undesired signals is due to the fact that the 3<sup>rd</sup> order IM Products for N+K & N+2K fall in channels N and N+3K. If either channel N or N+3 is the channel to which the receiver is tuned, these 3<sup>rd</sup> order distortion products fall in the desired channel, appearing as noise; Co-Channel Noise. Reception fails if the co-channel noise is 15 dB below the desired DTV signal power.

What the FCC Report has shown in the single interferor tests except for the N+7 problem uncovered by the FCC) they performed marginally against an interferor on an adjacent channel, well against a single interferor offset by more than one channel but poorly when there are two interferors each offset by more that one channel. By implication, more than two interferors offset by more than one channel might cause even more jamming.

However the FCC Report also showed that where there were pairs of undesired signals on any of the channel pairs of the form N+K and N+2K they were much more subject to jamming; the data shown here shows the increased susceptibility to jamming is up to 15 dB.

### **Recent laboratory experiments of multiple Interferors by the author.**

The FCC data for two interferors on those channel pairs which increase the noise floor under the desired signal, suggested to the author that further experiments with more than two interferors would be worthwhile. He has investigated triplets of undesired DTV signals and reported even more serious interference problems.

There are two kinds of triplets of undesired signals; symmetrical triplets such as channels 30, 33 & 36 and asymmetrical triplets such as 30, 32 and 37. In the FCC Table of Permanent Channel Assignments, he found 203 triplets in the same communities, 161 of which are asymmetrical and 42 symmetrical. His search range was for channel offsets from 1 to 9 only. Of these, 111 have offsets from 1 to 5 inclusive which means that most of the triplets in these communities are tightly packed. This has implications for the planning of Translator channels.

The author's results for those triplets with offsets in the range of 1 to 5 channels are attached.

What they demonstrate is that asymmetrical triplets spread their 3<sup>rd</sup> order distortion products over a very large number of channels below and above the triplet.

### **How does this relate to Translators?**

The signal from an unlicensed device near a DTV receiver will be received by the DTV antenna and fed to the DTV receiver. In a previous NTA presentation the author showed that one unlicensed signal radiated 100 feet from the DTV antenna would be - 12.2 dBm at the DTV receiver input. This is roughly 10 dB above the power at which many DTV receivers overload. Therefore one unlicensed transmitter may jam DTV reception next door, across the street, or in the same apartment house, to say nothing of what it would do if the unlicensed device were in the same apartment as the DTV receiver. With more than one unlicensed device in use nearby, reception would be more severely affected as shown by the broad spectrum generated by triplets of signals one or all of which might be from unlicensed devices nearby.

Your audience is going to experience erratic DTV reception and of course they will look to you to solve 'your' problem with 'your' translator. Now you know that the source of such erratic DTV reception may be unlicensed transmitters near the affected receiver, and not 'your translator'.

### **So Where are White Spaces Within the Broadcast Spectrum?**

They are few and far between as shown above when compared to the large numbers claimed by the New America Foundation.

The differences are due to:

1. The incorrect assumption that adjacent channels can be used by unlicensed devices operating on "vacant" TV channels.
2. That DTV receivers are linear devices that are not subject to overloading by undesired signals within the power range of received DTV signals, - 8 to - 84 dBm.

Whatever deficiencies in interference rejection were exhibited by receivers tested to date, the author believes that those receivers did not use an IC implemented Tuner-on-a-chip. These were all single conversion tuners built of discrete components packaged in a metal box ("can Tuners"). Tuners implemented on an IC have been announced and said to be in production, however the author is not aware of any DTV receiver presently being marketed in the U.S. which has a silicon single conversion tuner. Some of the NTIA Coupon Eligible DTV Downconvertors have a Double-conversion Silicon (IC) Tuner.

Double conversion tuners may provide improved interference rejection because the Surface Acoustic Wave Filter first IF Filter (SAW Filter) can reject all but the first adjacent channel undesired signals. However the Low Noise RF Amplifier and First Mixer of such double conversion tuners must not suffer overloading by multiple signals which may be up to  $-8$  dBm.

Hopefully, the FCC will propose a set of Rules based on thorough and well founded testing, governing the deployment of these unlicensed devices which minimize interference to DTV reception. Perhaps it will prohibit use of adjacent channels, and may also restrict the maximum radiated power of all such devices.

Thank you for your kind attention.